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SCIENTIFIC AMERICAN

JANUARY 2000

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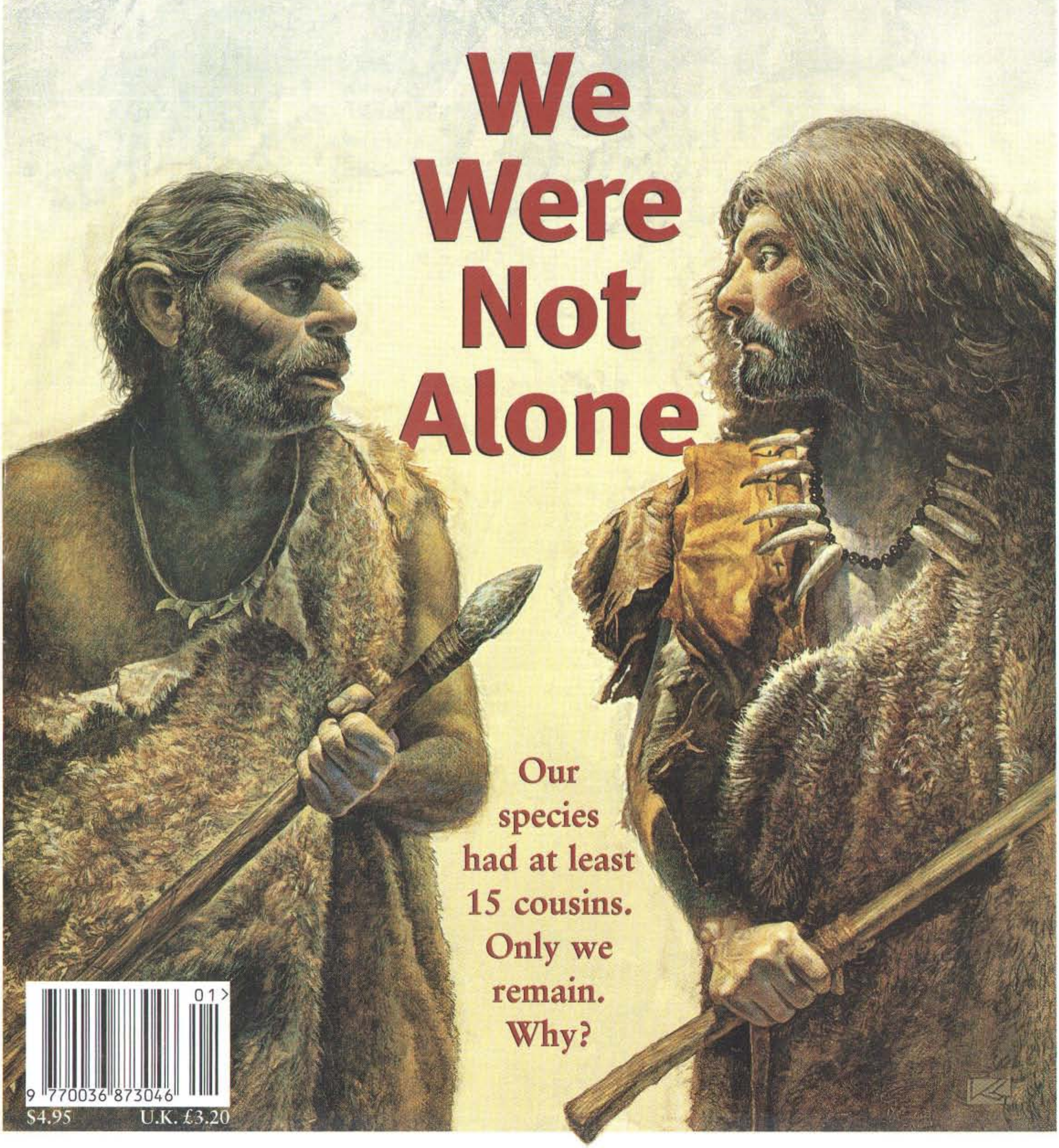

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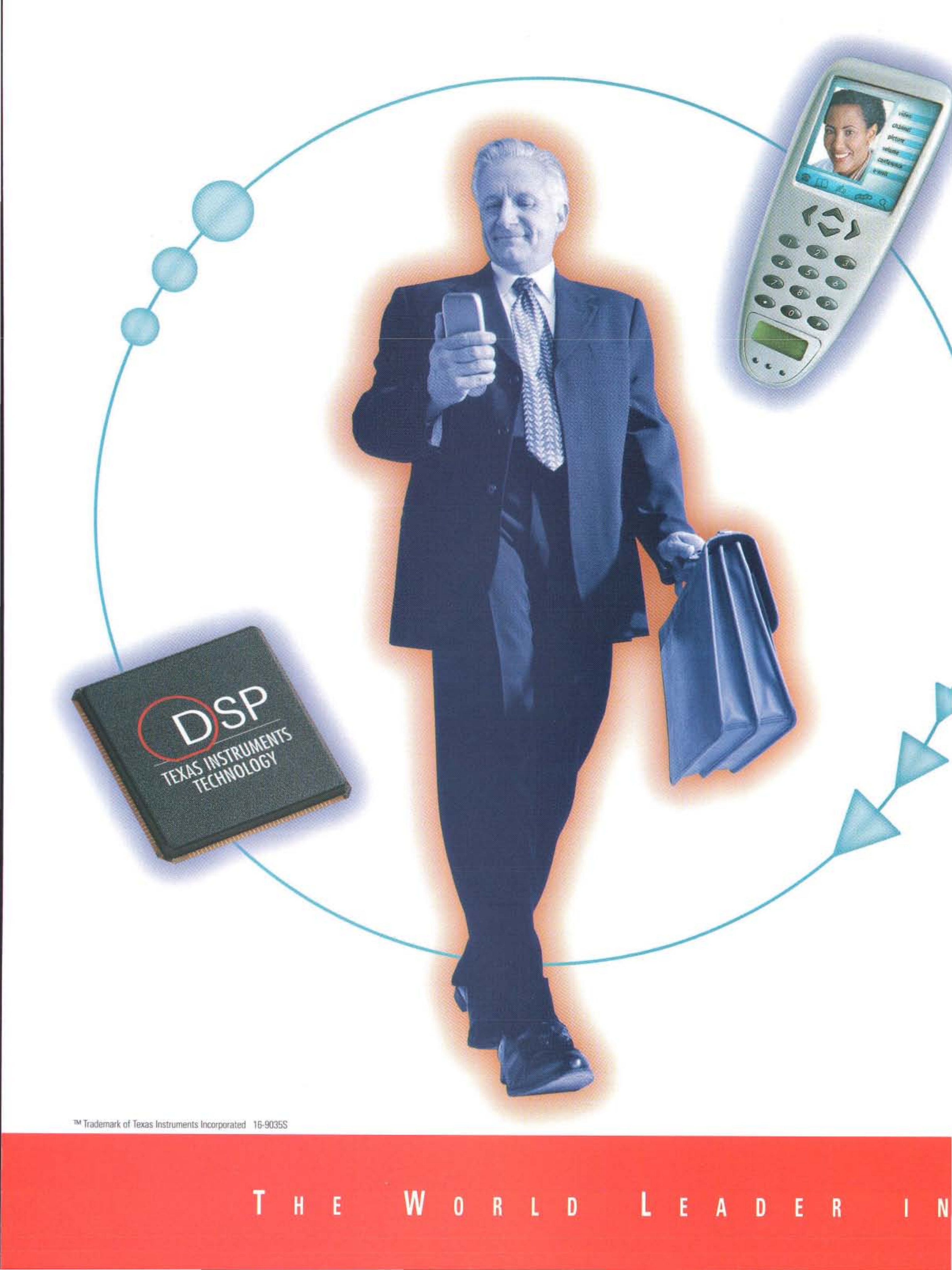

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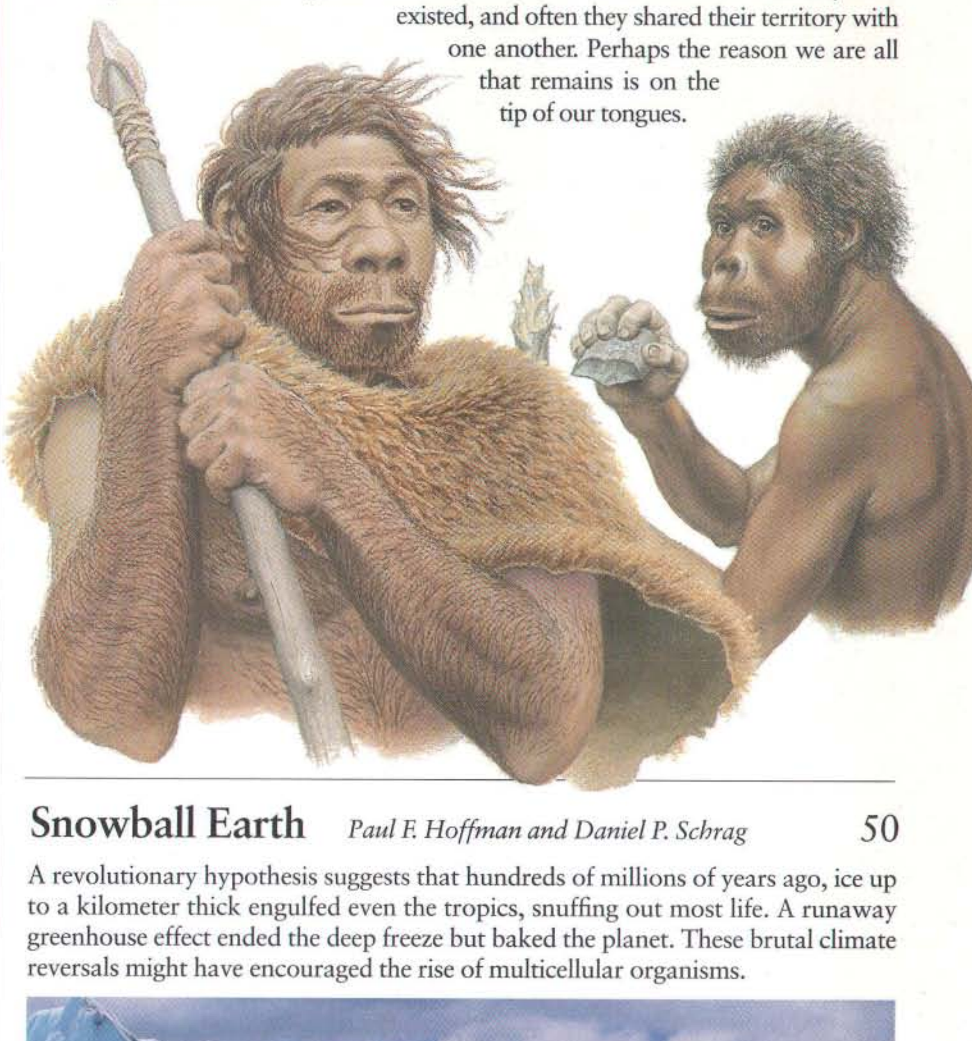

About the Cover

A Neanderthal and a modern human inspect each other in this painting by Kazuhiko Sano.

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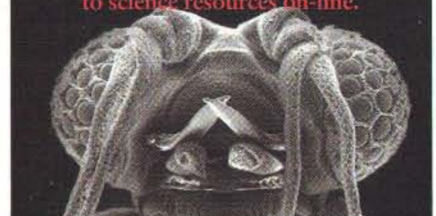

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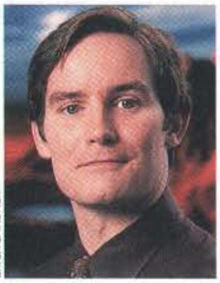
FROM THE EDITORS

Warp Drive Goes Here

What we need is a large crate, say about four feet on a side. I'm not sure where we'll put it in our offices, but where else can we file all the mail that I'm expecting in response to the article "Negative Energy, Wormholes and Warp Drive"?

Faster-than-light starships, time travel and weird quirks of physics clearly touch a nerve in many of our readers. I'll put this diplomatically: SCIENTIFIC AMERICAN already gets a certain number of letters every month from people who maintain that they have devised workable plans for interstellar spaceships. (We're not special in this regard; every science magazine does.) These correspondents generously include the blueprints, which are lovingly detailed except around the drive systems. There the plans get sketchy, with remarks about brackets for supermagnets or black holes in bell jars or other exotic components. The most straightforward ones just present a blank box labeled "Warp Drive Goes Here."



ERICA LANSNER

Negative energy might be what you feel when looking at IRS instructions for tax forms.

Physicists Lawrence H. Ford and Thomas A. Roman, beginning on page 30, give a legitimately scientific perspective on what ought to be in those blank boxes. As their fascinating article describes, the laws of physics in principle permit one to circumvent the light-speed barrier by creating shortcuts through intensely warped volumes of space. Those same methods can also make possible a form of time travel. All you need is to generate and apply enough negative energy.

And what is negative energy? It is not merely the absence of energy, or some property of antimatter—those would be a little too obligingly easy to tame. I like to think negative energy is the paralyzing force that sweeps the earth on Sunday afternoon at 4 P.M., when you suddenly realize the weekend is almost over. Or what you feel when looking at the Internal Revenue Service's instructions for completing a tax form. It is why the Boston Red Sox cannot win a World Series. It is New Age music played at half-speed. Good luck doing anything useful with that.

Alas, in our quest to go faster than light, principle may be on our side, but it is possible that pragmatism is not. We might turn out to be too big to fit through wormholes; *worms* might be too big; the protons and neutrons in our atoms might be too big. To the extent that wormholes through space and through time are equivalent, I suppose that might explain why we are not awash with time-travel paradoxes: the limited porousness of space-time may keep us barricaded like a screen door.

Such speculations are just what I expect readers to share in their letters. So write! I'll go find a crate.

John Rennie

JOHN RENNIE, *Editor in Chief*
editors@sciam.com

LETTERS TO THE EDITORS

Edward J. Larson and Larry Witham's article, "Scientists and Religion in America" [September 1999], drew numerous—and highly varied—responses. Some expressed disdain for either science or religion; others lamented that conflict exists between them. Several readers criticized the methodology of the survey on grounds such as its neglect of the many religions other than Christianity, and a few wished the same energy that goes into the science-religion debate could be redirected to improving the world. "Belief means what you can bet on," writes Charles Walton of Los Gatos, Calif. "I will bet on the theory of relativity, I will bet on evolution and natural selection. One cannot bet that God will protect the innocent, or that God will save a deserving life, or that God answers prayers. The best thing for us to do," he opines, "is get on with our daily work and creatively advance humankind's understanding. In that way we can hope to find the truth about God or whatever is behind it all." Additional comments on this article and others in the September issue follow.

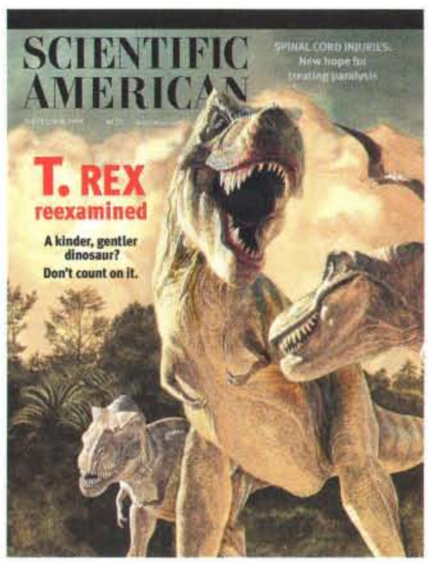
SCIENCE AND RELIGION

With regard to "Scientists and Religion in America," by Edward J. Larson and Larry Witham, conflicts between science and religion are not initiated by science. They occur when science proves (or appears about to prove) false a "truth" claimed by one or more mainstream religions. Religion and philosophy simply must accept that if they claim to have special knowledge of the material world they are at risk of being proved wrong. Attacks on science are no different than the once acceptable practice of killing the messenger.

TIERNEY JAMES
via e-mail

Saint Thomas Aquinas wrote the definitive paper on science and religion. In his treatise Aquinas reconciled the two disciplines, urging that faith and knowledge of the "senses" (science) are not only compatible but complementary. To him, the mind was the greatest gift God gave us. Aquinas realized more than 700 years ago a concept with which we struggle even today—that knowledge external to scripture does exist and that God meant for us to pursue it. We are currently on the brink of great scientific progress. But we are also in danger of retreating into another dark age. I hope we have the courage to avoid the latter.

KEN L. GOULD
North Little Rock, Ark.



SEPTEMBER ISSUE inspired lots of readers to write in, commenting on everything from religion to T. rex.

The debate would be helped if more theologians and philosophers, as well as the general public, had a better understanding of science. Likewise, narrowly focused scientists would do well to expand their understanding of theology, philosophy and history. The statements made to Ernst Mayr by a scientist that "I just couldn't believe that there could be a God with all this evil in the world" indicates an appalling lack of theological and philosophical grounding. On the other side, the arguments of creationists have been debunked so many times it's a wonder the issue continues to emerge.

That Christian conservatives are able to push the creation-science agenda at the public school level is in part a result of the public's lack of knowledge about the people they elect and the science-challenged voting public's lack of appreciation for real science. As usual, education is a key to understanding.

CHRIS L. MORGAN
Kansas City, Mo.

COYOTE CALLS

I enjoyed the excellent article "The Throat-Singers of Tuva," by Theodore C. Levin and Michael E. Edgerton. Throat-singing is shared by the lowly coyote, which can simultaneously utter a yelp, yodel and howl—sounding like a pack of animals in pursuit of prey. This probably led to the notion that coyotes run in packs, which they actually do only occasionally.

WILLIAM H. PECK
Hillside, Ariz.

T. REX TACTICS

In "The Teeth of the Tyrannosaurs," author William L. Abler's speculation about the consequences of septic bites may be misleading. Unlike contemporary Komodo dragons, tyrannosaurs did not have any large mammalian prey that might be affected by septic bites. Reptiles and birds rarely develop septicemia after sustaining septic wounds. This may be because of a primitive inflammatory response that immobilizes the bacteria in the wound through the exudation of fibrin. The same immobilization of bacteria would probably have occurred in dinosaurs, too, and would have allowed nonfatally wounded tyrannosaurs or prey to recover.

FRITZ HUCHZERMEYER
Onderstepoort, South Africa

CALENDRICAL MISCALCULATION?

In the fiction excerpt "The Dechronization of Sam Magruder," by George Gaylord Simpson, with commentary by Gregory M. Erickson, one detail went unexplained. The supposed start date of the time-travel experiment was February 29, 2162—a date that does not

exist in our current calendar system. I doubt that such an error would slip past the keenly observant Simpson, so I must assume that the world of the novel includes a calendar reform.

DAVID J. SCHULLER
Department of Molecular Biology and Biochemistry
University of California, Irvine

NUCLEAR STOCKPILE WITHOUT STEWARDSHIP?

Christopher E. Paine's article, "A Case against Virtual Nuclear Testing," highlights several weaknesses in the U.S. plan to maintain nuclear weaponry in a test-free world. But his proposed alternative—to certify a few reliable weapons now and simply manufacture them in the future if necessary, thus obviating the need for weapons scientists—is much worse. Do we really want a nuclear stockpile without the cadre of scientists who understand them? Paine forgets that the greatest asset in our nuclear arsenal is people. People can build new weapons, diagnose problems and interpret intelligently the signs of nuclear buildup in other countries. Bright physicists and engineers cannot be attracted into weapons work just to read blueprints, nor is textbook learning sufficient to understand the subject.

The stockpile stewardship and management program, with its cutting-edge experiments and computers, offers such training. Indeed, it is the most important purpose of the program.

WADE WILLIAMS
Lawrence Livermore
National Laboratory

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ERRATUM

In "Working Knowledge" [September 1999], the flight path of the batted baseball would have been better described as parabolic.

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50, 100 AND 150 YEARS AGO

SCIENTIFIC AMERICAN

JANUARY 1950

THE U.N. VERSUS MASS DESTRUCTION—"I know there are people whose efforts seem to be directed to pointing out how irreconcilable is the gulf that splits the world today rather than to seeking ways to bridge it. All of us should know by now that another war with the weapons of mass destruction now available would destroy all existing political, economic and social systems and set civilization back by a thousand years. Every action of the U.N. that contributes to the lessening of tension between East and West, that develops the processes for the peaceful settlement of disputes among all nations, will help to prevent atomic destruction. —Trygve Lie, Secretary General of the United Nations"

IN THE LIGHT OF EVOLUTION—"The most serious objection to the modern theory of evolution is that since mutations occur by 'chance' and are undirected, it is difficult to see how mutation and selection can add up to the formation of such complex and beautifully balanced organs as, for example, the human eye. It would indeed strain credulity to suppose that a lucky sudden combination of chance mutations produced the eye in all its perfection in the offspring of an eyeless creature; it is the result of an evolutionary development that took millions of years. Along the way the evolving rudiments of the eye passed through innumerable stages, all of which were useful to their possessors. —Theodosius Dobzhansky"

JANUARY 1900

RADIUM—"Sklodowska Curie has endeavored to determine the atomic weight of radium. She subjected to fractional distillation a mass of purified radiant barium chloride, obtained from half a ton of uranium residues supplied by the Austrian government. The values thus obtained varied from 140 to 145.8, as against the atomic weight of inactive barium 137.7 found at the same time. This leaves the atomic weight of 'radium' indeterminate, but it is clear that radium is not allotropic barium, since no allotropic forms of an element have different atomic weights."

ZULU—"Statisticians assert that there are eleven hundred and fifty-one distinctive tribes of natives in South Africa, south of the Zambesi River, including the Zulu. The Zulu's cuticle is transparent—so much so, that the red blood can be seen coursing beneath it. That is the Zulu's greatest pride. He will point to his skin to prove that he is a pure-bred Zulu. The accompanying photograph shows two unmarried Zulu. One peculiarity that will interest bachelors is that the married men have a band drawn around their hair, while those still in single misery are without this emblem."

Zulu of southern Africa

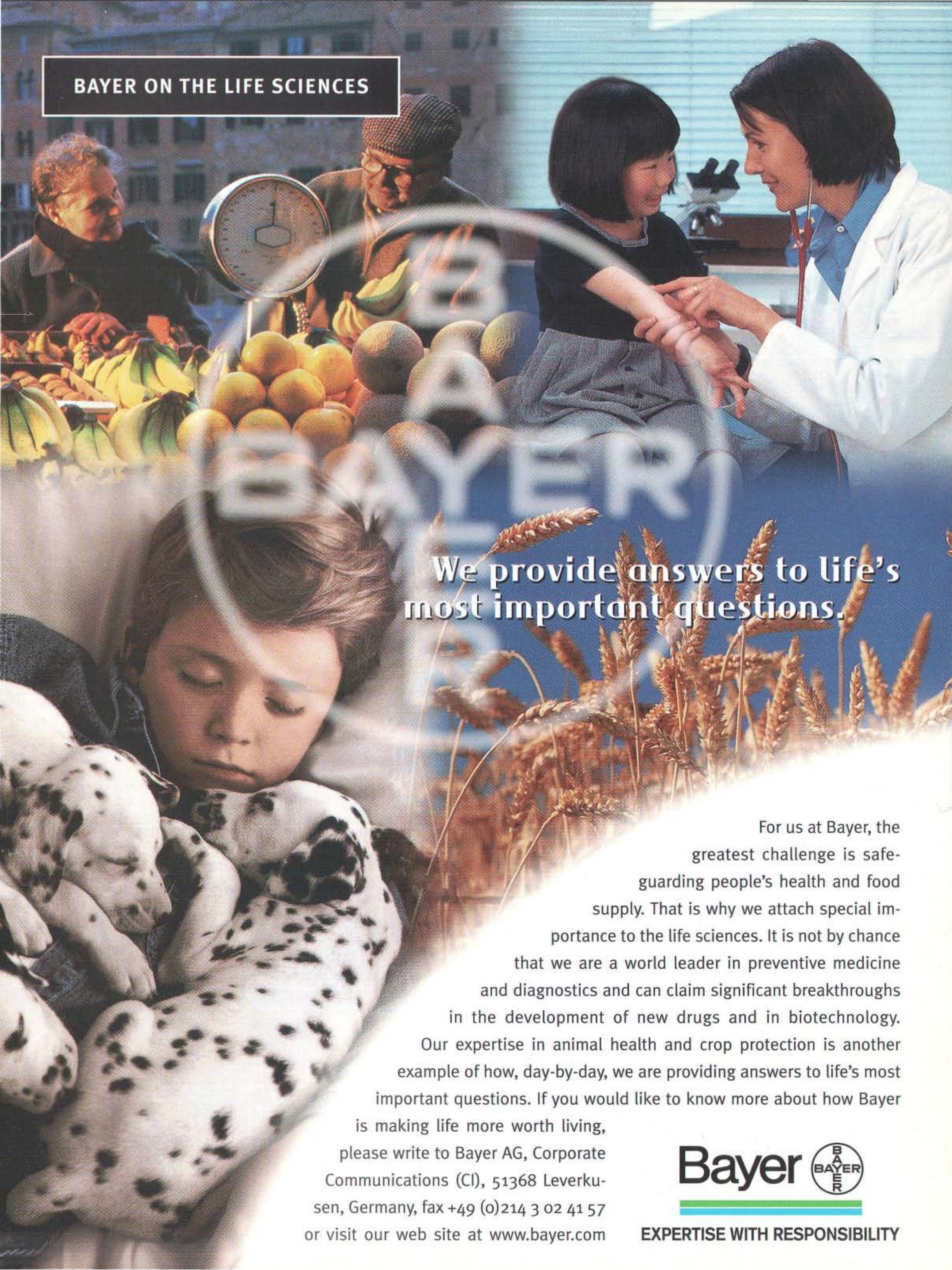
LAST OF THE BUFFALO II—"To the Editor: 'What rational mind could look with favor on a great herd of a million buffalo charging madly upon every settlement and line of fence from Minnesota to Texas? Where once roamed unfettered the pioneer of the prairies, now graze in quietude countless herds of cattle. Enough buffaloes remain for museum purposes.'"

NEW CENTURY—"In the daily press we find a fierce epistolary battle raging between those who believe that the year 1899 marks the close of the nineteenth century and those who hold that not until 1901 shall we cross the threshold to the new era. It seems so difficult to understand that 1800, 1900, 2000, designates not the beginning, but the end of a century. It is evident that there never was a year 0, that the century must begin with a 1. A hundred years ago the same wordy war was waged; a hundred years hence it will be renewed."

JANUARY 1850

NEW PRUSSIAN RIFLE—"News of the famous Prussian breech-loading rifle: the light infantry of the Prussian army are all armed with this fearful weapon, and in the late war with the Danes, and in some encounters with the people, it proved terribly advantageous on the side of Prussia. It is very different from all other breech-loading fire-arms. It uses a different cartridge and no detonating powder, but a friction needle—*darting* needle (*zund nadel*)—which pierces the bottom of the paper cartridge and ignites the powder by a friction combustible priming. It is as efficacious in wet as in dry weather. It carries a ball 800 yards, and is as effective at that distance as muskets at 150. Ten shots can be fired by it in one minute." [*Editors' note: The Dreyse rifle is considered to be the forerunner of all modern breech-loading rifles.*]

CHEMISTRY OF THE STARS—"It is shown to be impossible that the system of animal and vegetable life of our globe can exist on other planets and heavenly bodies. The dry and rugged surface of the moon, volcanic, yet without sea or atmosphere, the varying quality of meteorites or air stones, so far as their component substances have been discovered by analysis, are among the data on which it is argued that the stars are not *telluric*, that they do not resemble the earth, and, therefore, that life must be differently sustained on those orbs."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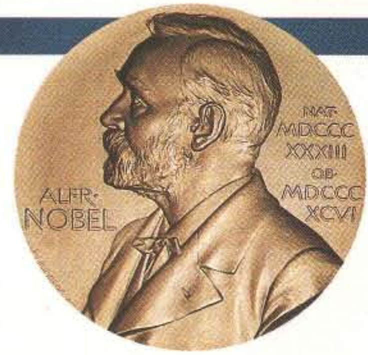
EXPERTISE WITH RESPONSIBILITY

The Nobel Prizes for 1999



AP/WIDE WORLD PHOTOS

Explanations of the science underlying the world's most prestigious awards for physics, chemistry and physiology—plus a look at the prizes for peace, won by a physicians organization, and economics

PHYSICS

DOING THE MATH

GERARDUS 'T HOOFT
University of Utrecht, the Netherlands

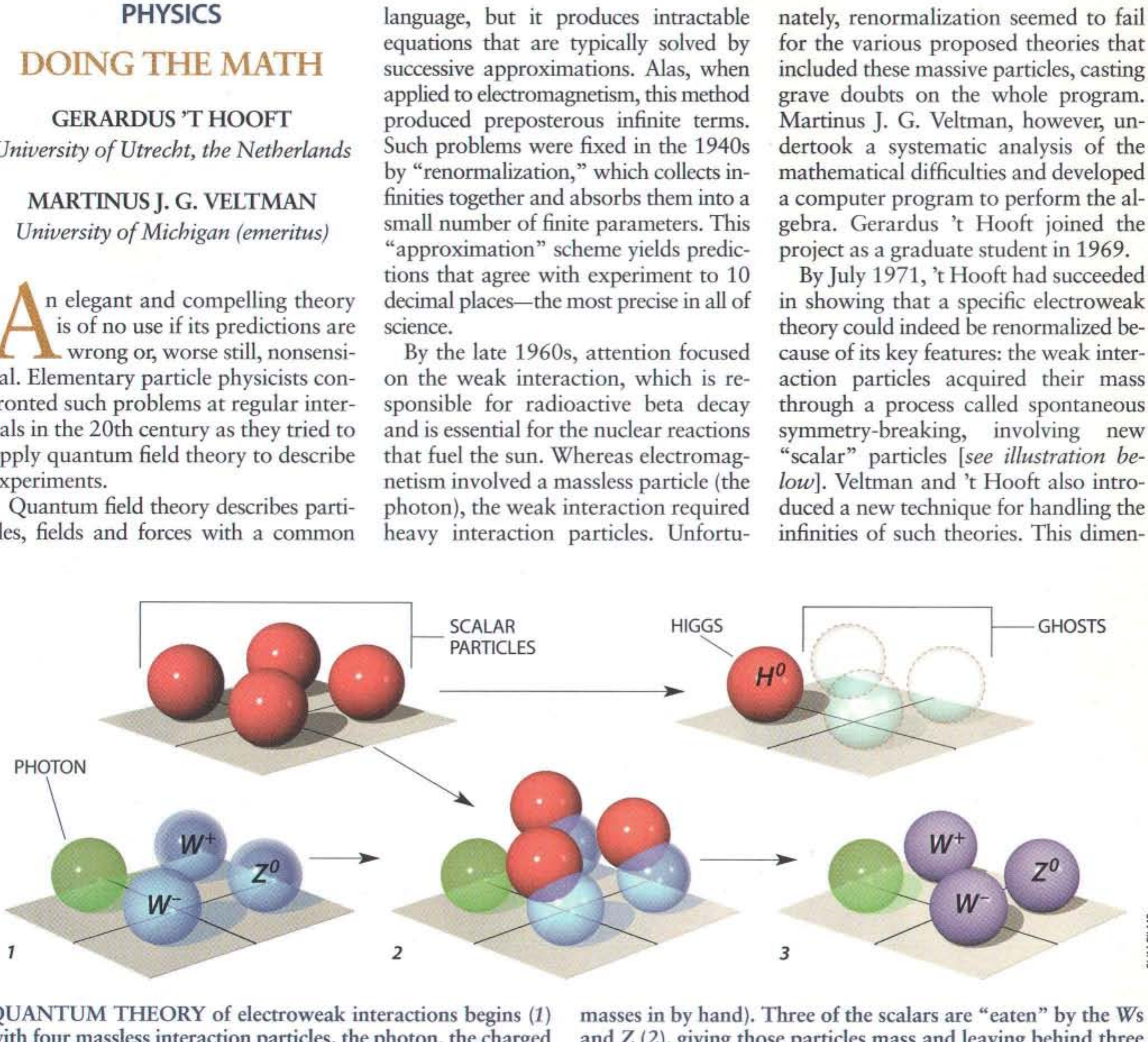
MARTINUS J. G. VELTMAN
University of Michigan (emeritus)

An elegant and compelling theory is of no use if its predictions are wrong or, worse still, nonsensical. Elementary particle physicists confronted such problems at regular intervals in the 20th century as they tried to apply quantum field theory to describe experiments.

Quantum field theory describes particles, fields and forces with a common language, but it produces intractable equations that are typically solved by successive approximations. Alas, when applied to electromagnetism, this method produced preposterous infinite terms. Such problems were fixed in the 1940s by "renormalization," which collects infinities together and absorbs them into a small number of finite parameters. This "approximation" scheme yields predictions that agree with experiment to 10 decimal places—the most precise in all of science.

By the late 1960s, attention focused on the weak interaction, which is responsible for radioactive beta decay and is essential for the nuclear reactions that fuel the sun. Whereas electromagnetism involved a massless particle (the photon), the weak interaction required heavy interaction particles. Unfortunately, renormalization seemed to fail for the various proposed theories that included these massive particles, casting grave doubts on the whole program. Martinus J. G. Veltman, however, undertook a systematic analysis of the mathematical difficulties and developed a computer program to perform the algebra. Gerardus 't Hooft joined the project as a graduate student in 1969.

By July 1971, 't Hooft had succeeded in showing that a specific electroweak theory could indeed be renormalized because of its key features: the weak interaction particles acquired their mass through a process called spontaneous symmetry-breaking, involving new "scalar" particles [*see illustration below*]. Veltman and 't Hooft also introduced a new technique for handling the infinities of such theories. This dimen-



SLIM FILMS

QUANTUM THEORY of electroweak interactions begins (*1*) with four massless interaction particles, the photon, the charged W^+ and W^- and the neutral Z^0. Experiment indicates that the *Z* and *W*s must be massive, but adding mass to the theory "by hand" spoils its mathematical consistency. Instead four additional scalar particles (*red*) are introduced (technically, they preserve the equations' underlying gauge symmetry, unlike adding masses in by hand). Three of the scalars are "eaten" by the *W*s and *Z* (*2*), giving those particles mass and leaving behind three "ghosts" and a scalar particle subsequently termed the Higgs (*3*). The ghosts, as befits their evocative name, occur only in ephemeral intermediate states. Veltman and 't Hooft developed the first consistent mathematical technique for deriving meaningful predictions for experiments from this theory.

sional-regularization method, which involves temporarily modifying the number of space dimensions in a calculation, was invaluable in wrapping up some details of the renormalization proof and became widely used.

The result encouraged theorists and experimenters to focus on the renormalizable electroweak theory, which has since become a core part of the Standard Model. The techniques pioneered by 't Hooft and Veltman allowed detailed predictions of properties of the W and Z particles and approximate predictions concerning the top quark, all of which have been confirmed by experiments. Two outstanding problems remain in this line of work: for experimenters, direct observation of the Higgs particle; for theorists, an equally tractable, renormalizable theory of quantum gravity.

CHEMISTRY

THE FEMTOSECOND CAMERA SHUTTER

AHMED H. ZEWAIL
California Institute of Technology

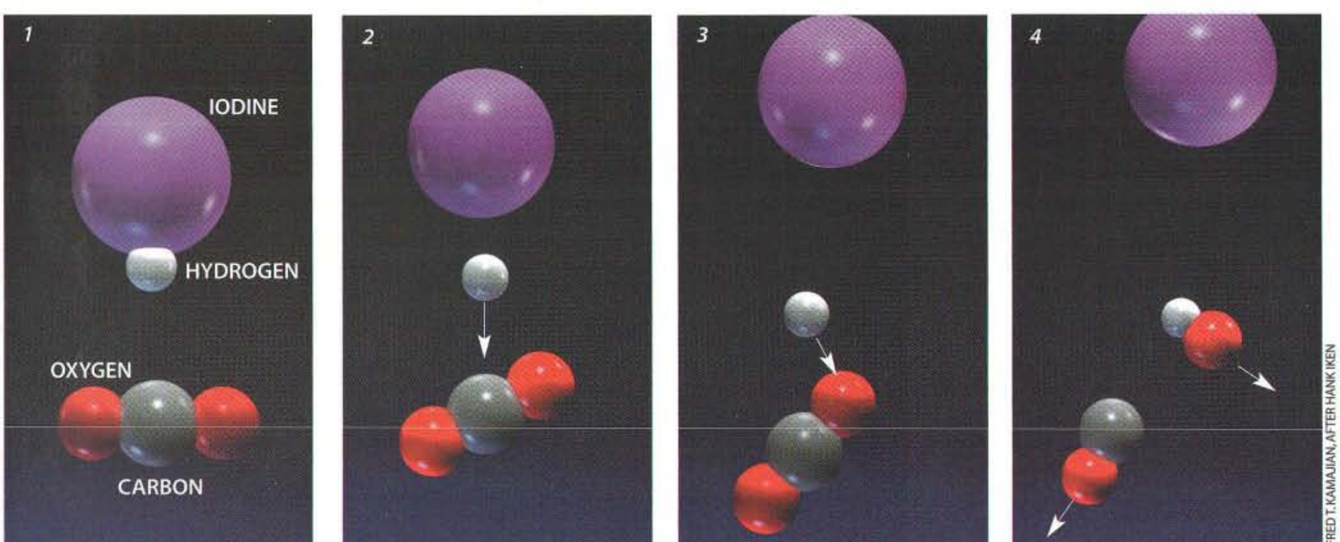
The ability to follow chemical reactions in minute detail has been one of the most relentlessly pursued goals in science. That kind of capability would help forge answers to fundamental questions, such as why certain chemical reactions occur and others do not, and why the rate and yield of a chemical reaction depends on the temperature at which it takes place.

The difficulty has been the extreme speed with which reactions occur. In a quarter-second blink of an eye, benzene and iodine molecules could react, producing atomic iodine and other products, more than 333 billion times.

In the late 1970s Ahmed H. Zewail began shining short laser pulses on molecules and atoms as they reacted, hoping to illuminate the dynamics in real time. During the reaction, transition states occur featuring molecules or atoms that are neither the reactants nor the products. These molecules and atoms absorb or reradiate any light falling on them, altering the spectrum of the incident light at characteristic frequencies.

Transition states last only 10 to 100 femtoseconds, so the laser pulses needed to probe them must be extraordinarily short. Lasers capable of emitting such pulses came along in the mid-1980s, and Zewail and his co-workers immediately saw their possibilities. Starting with cyanogen iodide (ICN) in 1987, they were able to observe telling details of the molecule's dissociation for the first time. They saw the molecule split into iodine and cyanide and even watched the fragments zoom away from one another.

In a typical experiment, Zewail initiates a reaction with a pump pulse, which energizes the reactants. The first probe pulse hits the molecules a few femtoseconds later and is followed by many thousands more, every 10 femtoseconds or so, for the duration of the reaction. Changes in the spectrum of each probe pulse reveal the state of any chemical bonds and the excitation levels and motion of the atoms and molecules. (For a complete discussion, see Zewail's SCIENTIFIC AMERICAN article, "The Birth of Molecules," in the December 1990 issue.) Researchers now use Zewail's technique to provide detailed insights into such phenomena as catalysis, photosynthesis and the light-driven molecular transition that occurs in the rods in the retina when the eye detects photons. As for Zewail himself, he says that "our latest effort is understanding the molecular structures of biological systems in real time—how the structures change from one configuration to another." As a preliminary foray into this field, he and his colleagues monitored the dynamics of the reaction in which ethylene is derived from ethane. The longer-term goal is to study the dynamics of protein molecules, the building blocks of life. Zewail believes it will ultimately be possible to alter molecules precisely using deftly placed pulses. Graduate students take note: there may even be another Nobel Prize in it.



REACTION between hydrogen iodide and carbon dioxide to create carbon monoxide, hydroxide and iodine was probed and recorded by Ahmed H. Zewail and his colleagues in the late 1980s. Using countless infinitesimally short laser pulses, the researchers could follow the sequence of events (*1–4*) and even the motions of the individual molecules and atoms.

PHYSIOLOGY OR MEDICINE

A CELLULAR ZIP CODE

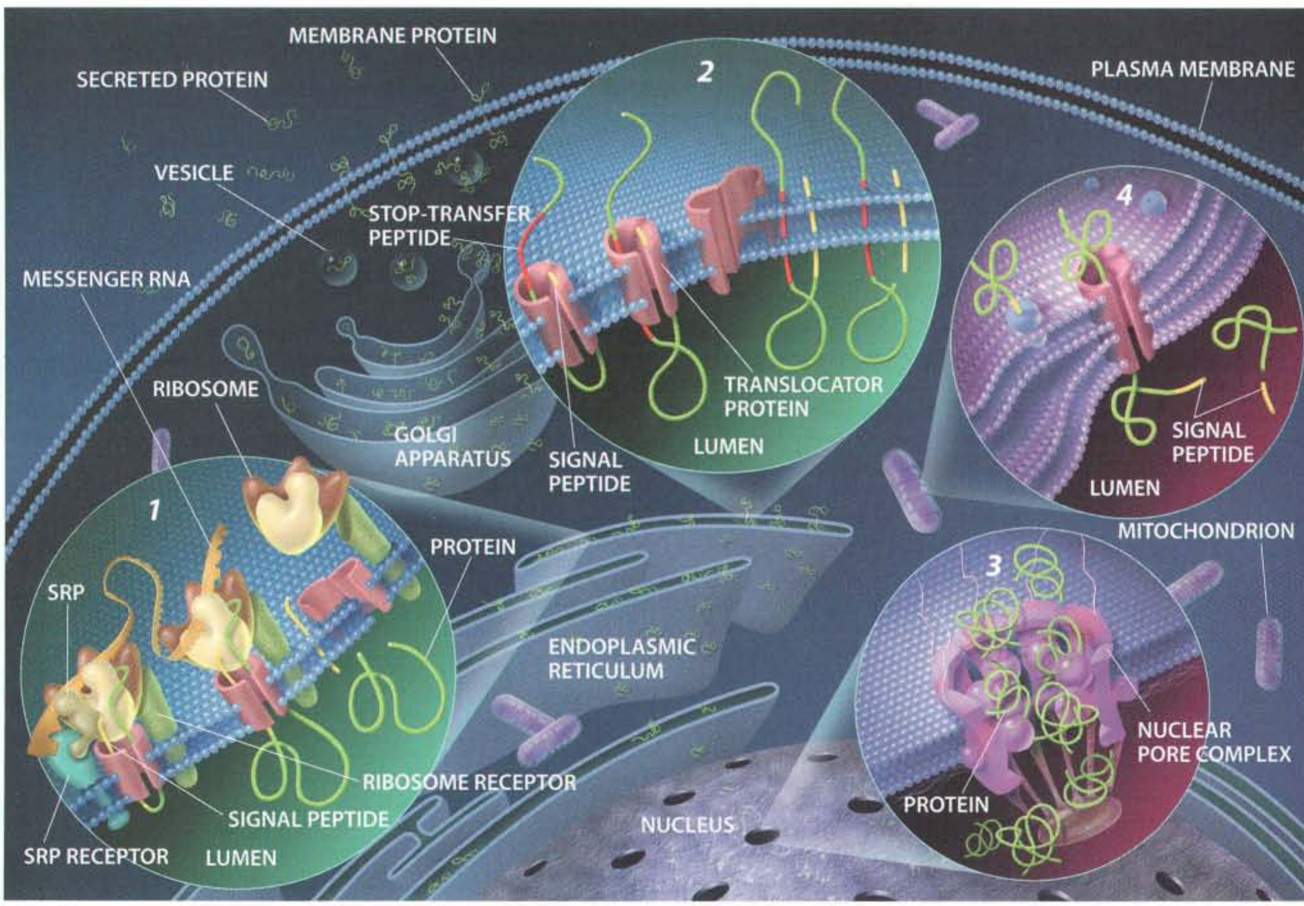
GÜNTER BLOBEL
Howard Hughes Medical Institute and the Rockefeller University

Oil and water don't mix. So how do proteins—watery, water-loving molecules that they are—traverse intracellular membranes, which are essentially oily barriers that divide a cell into various compartments? That question launched biochemist Günter Blobel on the research path that culminated in his receiving the 1999 Nobel Prize in Physiology or Medicine.

The first key to understanding how proteins move across membranes came in 1971, when Blobel was working in the laboratory of George Palade at the Rockefeller University. Blobel and his colleague David Sabatini proposed that each newly made secreted protein has a short stretch—which they called a signal peptide—at one end that allows it to snake through a membrane's fatty environment.

Over the next three decades, Blobel expanded the signal hypothesis by figuring out how the process of protein translocation works and by discovering that signal peptides also serve as "zip codes" for directing new proteins to their correct places within a cell, as depicted in the illustration below. The process is a universal one: it operates similarly in plant, yeast and animal cells, including those of humans.

Many serious diseases—such as cystic fibrosis and familial hypercholesterolemia, a genetic disorder that leads to very high blood cholesterol levels—arise when the protein-addressing system of a cell goes awry. Blobel's findings are paving the way to a better understanding of the causes of and the potential treatments for these disorders.



PROTEINS CROSS MEMBRANES at many places within a cell. Those destined for secretion—such as some hormones—spool off ribosomes as they are synthesized (*1*) and enter the endoplasmic reticulum. Short sequences called signal peptides help to direct ribosomes to the endoplasmic reticulum by binding to signal-recognition particles (SRPs), which in turn bind to SRP receptors. The signal peptides are cleaved off once the proteins are translocated across the endoplasmic reticulum. The proteins are packaged into membrane vesicles that subsequently pass through the Golgi apparatus and fuse with the cell's plasma membrane to spew their contents.

Proteins that will remain stuck in the cell membrane, such as receptors for receiving biochemical messages from other cells, go through a similar pathway (*2*). Besides a signal peptide, however, transmembrane proteins also have a "stop-transfer" peptide that keeps them anchored in the membrane. When vesicles bearing the proteins drift to and fuse with the plasma membrane, the proteins become integral parts of the membrane.

A different type of signal peptide allows proteins that act in the nucleus (*3*), where the genes reside, to home in on specialized structures called nuclear pore complexes. Other signal peptides ensure that proteins with jobs in various cellular organelles—such as the energy-producing mitochondria (*4*)—get to their appropriate positions within the cell.

ECONOMICS

GODFATHER OF THE EURO

ROBERT A. MUNDELL
Columbia University

Referring to Robert A. Mundell, winner of the 1999 Bank of Sweden Prize in Economic Sciences in Memory of Alfred Nobel, the citation from the Royal Swedish Academy of Sciences states that "his most important contributions were made in the 1960s." But with an emphasis on international trade, exchange rates and the benefits of a common currency, Mundell's research couldn't be more timely in this age of globalization.

Currently at Columbia University, Mundell worked at the International Monetary Fund (IMF) and the University of Chicago during the 1960s. At that time, he developed a now famous model of international trade called the Mundell-Fleming model. (Marcus Fleming, who was also an economist at the IMF, died in 1976.)

In putting together the model, Mundell was particularly interested in the consequences of foreign trade and the movement of capital across national borders. His research showed that rates of exchange between currencies have a significant influence on the efficacy of a country's monetary policies (the supply of money available and changes in national interest rates) and fiscal policies (taxation and federal budget considerations). According to the Mundell-Fleming model, under a fixed exchange rate, changes to monetary policies would have little effect on a nation's economy, but fiscal policies would be quite powerful. The reverse is true under a floating exchange rate.

Today most countries operate under a floating exchange rate, with capital moving freely across international boundaries—and hence monetary policies tend to dominate. Notably, though, this was not the case in the 1960s. At that time, most nations (with the exception of the U.S. and Canada) limited the flow of capital across borders, and leaders simply did not take international economics into consideration when developing domestic agendas.

Also at that time, Mundell developed the idea of what he called "optimum currency areas"—countries in one area that would relinquish their individual currencies in favor of a common one. The European Union has recently adopted a single monetary unit, called the euro; indeed, Mundell has referred to himself as "a godfather of the euro." His 1968 book, *International Economics,* can be found at http://www.columbia.edu/~ram15/ietoc.html on the World Wide Web.

PEACE

PRESCRIPTION FOR PEACE

DOCTORS WITHOUT BORDERS/ MÉDECINS SANS FRONTIÈRES

For many of the world's injured and sick, impoverished and often war-ravaged, the only access to medical care is the international relief organization Doctors Without Borders/Médecins Sans Frontières. Currently more than 2,000 Doctors Without Borders volunteers are in 80 countries around the world, at least 20 of which are in conflict. The Nobel committee recognized the group's achievements by awarding it the 1999 Nobel Peace Prize.

In 1971 a group of French doctors, most of whom had worked for the International Committee of the Red Cross, decided to split from the older organization (whose founder won a Peace Prize in 1901). Their idea was to create a nonmilitary, nongovernmental organization specializing in emergency medical assistance that would also speak publicly against the individuals or governments responsible for the grim conditions the doctors were treating. This approach stood in stark contrast to agencies such as the Red Cross, which is always careful to stay neutral in political or diplomatic disputes.

In the early years of the organization, Doctors Without Borders offered assistance to Nicaraguans after the 1972 earthquake and to Hondurans hit by Hurricane Fifi in 1974. In 1975 Doctors Without Borders went to Vietnam, the group's first mission in a war zone. During the 1990s, the organization has intervened to assist, among others, Kurds, African citizens from the Democratic Republic of Congo, Sudan and Sierra Leone, people in Honduras, Kosovo, Chechnya and Afghanistan.

© ROGER JOB Doctors Without Borders

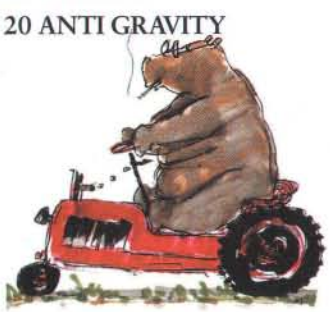
VOLUNTEER from Nobel Peace Prize–winning organization Doctors Without Borders assists at a clinic in Liberia.

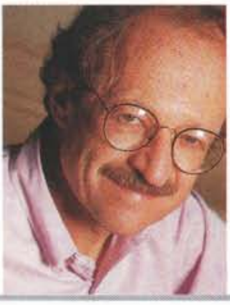
For many of the ailments Doctors Without Borders personnel see, the main hurdle to proper treatment is access to medication and supplies. For instance, in a report released in 1999, volunteers found that patients in Siberian hospitals were dying because they did not have access to the latest cocktails of antibiotics needed to cure drug-resistant forms of tuberculosis. Doctors Without Borders leaders are actively campaigning to remedy this problem with help from institutions such as the World Trade Organization.

In accepting the prize, James Orbinski, a doctor himself and president of the organization, stated that "as entire families are chased from their homes in East Timor and as thousands more are targeted in conflicts around the world that don't make headlines, the Nobel Prize is an important confirmation of the fundamental right of ordinary people to humanitarian assistance and protection." The organization's site is at http://www.msf.org/ on the World Wide Web.

Reported by Graham P. Collins, Carol Ezzell, Sasha Nemecek and Glenn Zorpette. For additional information on the prizes, visit www.sciam.com/explorations/1999/101899nobel/index.html on the Scientific American *Web site.*

NEWS AND ANALYSIS





IN FOCUS

MELTING AWAY

The shrinking of an immense swath of Antarctic ice threatens to raise sea level—and there may be no stopping it

For years, scientists have feared that the earth's ever toastier climate could melt enough polar ice to swamp populated coastal areas such as New York City. Of greatest concern is West Antarctica, which by itself harbors enough water in its frozen clutches to raise sea level by the height of a two-story home.

CANADIAN SPACE AGENCY © 1997

STREAMS OF ICE draining the interior of West Antarctica were imaged recently by satellite radar. White streaks reveal areas cracked by the motion of the adjacent ice.

Now new geologic evidence and one-of-a-kind satellite images are shedding light on West Antarctica's disappearing act. The bad news: the ice sheet may continue to shrink whether or not humanity curbs its release of heat-trapping greenhouse gases. The good news: its potential collapse may be slow enough that people will have time to move their cities out of harm's way.

Scientists worry about the West Antarctic ice sheet more than its counterparts in East Antarctica and Greenland, which cover bedrock that sits well above sea level. In contrast, West Antarctica's rocky foundation lies up to 2,500 meters below the ocean surface. The danger is that if the ice shelves that extend seaward from the continent start floating higher, they may pull the "grounded" ice away from the bedrock, making it more apt to crack into icebergs and melt. A complete breakup of the ice sheet, which is about the size of Mexico, would raise sea level by five or six meters.

For the first time, researchers have dated the retreat of the ice sheet's contact with the ground—a good way to determine how fast it is disappearing. Brenda L. Hall of the University of Maine and her colleagues knew from previous research that the ice sheet had extended 1,300 kilometers beyond its current position in the Ross Sea Embayment at the peak of the last ice age, 20,000 years ago.

As the planet warmed, the ice that had gripped much of North America melted, the oceans swelled and the grounded ice in West Antarctica pulled away from the bedrock in response. To find out just how fast this separation happened, Hall and her team needed to figure out the age of a beach that had formed along the ice sheet after its first known step

inland. The bits of organic matter needed to perform radiocarbon dating are difficult to come by in the barren Antarctic landscape. Trowels and tweezers in hand, Hall and her team often hiked 30 kilometers a day, scouring the rocky soil for the mollusk shells and sealskin that prove that seasonal open water must have existed there in the past.

Radiocarbon dates for the shells found at the oldest beach, which today juts out into the Ross Sea near McMurdo Sound, indicate that the region was free of grounded ice by 7,600 years ago. And based on organic beach material and radar images of the subsurface ice at two points farther inland, the ice has been retreating at an average rate of 120 meters per year ever since.

While Hall's team plotted how fast the edge of the ice sheet has been shrinking, a different research group has found evidence of when the ice began its retreat—using rocks stranded along the flanks of Mount Waesche volcano, which sits in the middle of the ice sheet and records the highest elevation the ice ever reached. "We use the volcano like a dipstick," says Robert P. Ackert, Jr., of the Woods Hole Oceanographic Institution. Ackert and his colleagues looked at the accumulation of cosmic particles that first struck the rocks when they were left exposed on the volcano, as the ice began to thin. The time that has passed since the rocks' exposure indicates that the ice did not begin its retreat until 10,000 years ago—at least 3,000 years after the oceans began to rise.

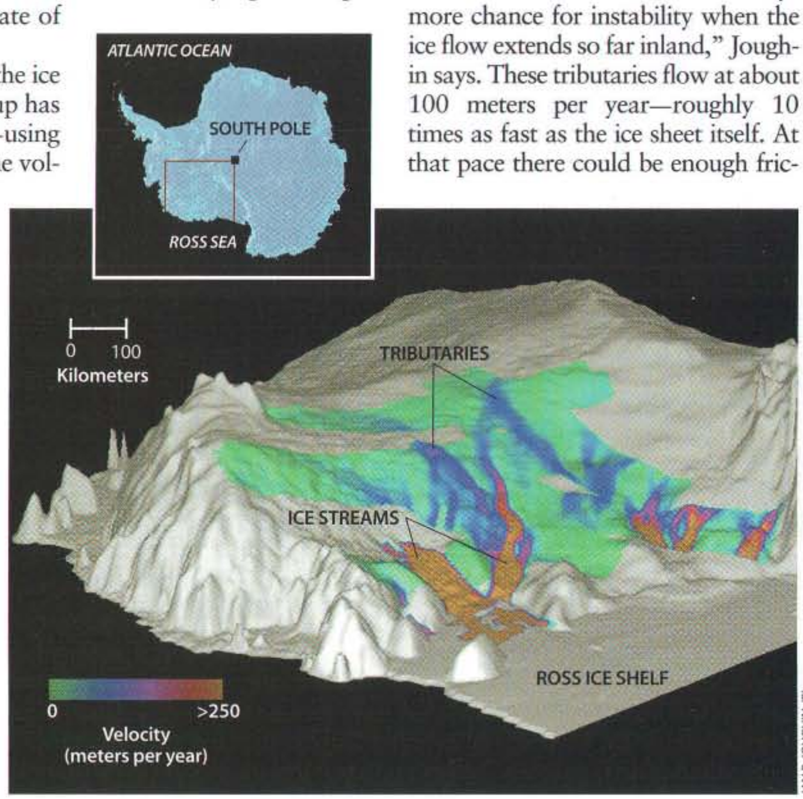
These findings together suggest that the ice of West Antarctica is slow to react and can continue to change even long after an external trigger—in this case, rising sea level—has stopped. What's more, the ice sheet shows no signs of halting its inland march, Hall says. At its current pace, it will disappear in 7,000 years regardless of global warming. But that prediction is extrapolated from only four past positions of the ice sheet. "We don't have enough data to know whether it has retreated in jumps and spurts," Hall notes.

Jumps and spurts are especially hard to predict because of the way the continent sheds its icy load. Antarctica may be shrinking, but oddly enough, it is not melting, at least not directly. Meltwater pours off Greenland's icy veneer, but in much colder West Antarctica "streams" of swift-moving ice do the shedding. Snow falls in the interior, and the streams carry ice to the sea, where it breaks into icebergs.

Until now, no one knew what was happening at the streams' source, but researchers are a giant leap closer to understanding just how these ice streams work, thanks to new images made by a Canadian satellite called Radarsat. On two occasions during the fall of 1997, the satellite measured reflections of cloud-penetrating radar over much of the ice sheet's thick interior upstream from the Ross Ice Shelf. Using a technique called interferometry, Ian R. Joughin of the Jet Propulsion Laboratory in Pasadena, Calif., and his co-workers mathematically compared the two sets of reflections to determine the speed and direction of the ice at each point [*see illustration above*].

"You don't see the picture until you connect all the dots," Joughin says. "That's what our image does." In times past, a single velocity measurement required that someone go to the spot and plant a stake with a Global Positioning System receiver in the ice, leave for a certain amount of time, then go back and see how far it had moved. In the barren chill of the Antarctic, that's no easy task. "The step forward is just remarkable," says glaciologist Richard B. Alley of Pennsylvania State University. "In the past we were really unclear about what the ice sheet looked like and how it changes."

Before Radarsat, some specialists had suspected a stable "lake" of accumulating snow might feed these swift streams, but it turns out that long tributaries nourish the streams from snowy regions deeper in the ice sheet's interior. "There's always more chance for instability when the ice flow extends so far inland," Joughin says. These tributaries flow at about 100 meters per year—roughly 10 times as fast as the ice sheet itself. At that pace there could be enough friction that the ice is actually melting along the bottom, he adds.



IAN R. JOUGHIN JPL

LONG TRIBUTARIES channel ice from West Antarctica's interior to speedier ice streams that flow onto the Ross Ice Shelf. Researchers mapped the motion by comparing the reflections of radar beamed from a satellite orbiting 800 kilometers above the ice surface (vertical relief is exaggerated).

Alley points out that lubricated streambeds are probably not new. Ice has been sliding quickly out of the interior for a long time, he notes: "Otherwise the ice would have been much thicker at Mount Waesche."

The satellite images also revealed that tributaries are still feeding one stream that previous researchers had given up for dead when it dammed up 140 years ago. That means if global warming melts ice elsewhere, rising sea level could tear up the Ross Ice Shelf and break the dam, which would allow ice from inland to flow faster, Joughin says.

Alley cautions that scientists are still far from being able to predict the fate of West Antarctica. "We'd like tell you whether it's going to fall in the ocean, but there's a lot of fundamental science we still just don't know," he says. This summer Alley and his colleagues will begin analyzing a kilometer-long ice core from West Antarctica that could reveal whether the ice sheet vanished in the warm times before the last ice age. If it did, that may give New Yorkers and the rest of the world more reason to be wary of a future meltdown. *—Sarah Simpson*

PSYCHOLOGY

NO SPACE SEX?

Despite a push to understand human behavior in space, NASA remains squeamish about sex

NASA

WORKING IN SPACE, such as assembling the International Space Station, could pose psychological challenges severe enough to endanger missions.

Even when humans aren't doing it, they are likely to be thinking about it. The representatives of the National Aeronautics and Space Administration, however, might be among the few who don't like to think about sex, at least not officially. But as permanent space habitation nears reality—the International Space Station could become home to men and women in as little as five years—there are signs that NASA may finally, albeit reluctantly, confront the issue of sexual behavior in space.

Astronauts and cosmonauts have lived in space for prolonged periods in the past, but the numbers on any one stint have been few. When the station is completed, crews of seven will serve tours of duty of up to 180 days. And proposed missions to Mars could take two and a half years to complete. Naturally, sexual behavior might occur on such long missions. It is a topic, however, that makes NASA publicists uneasy—as if the issue could somehow make astronauts seem to have less of "the right stuff." (Rumors of unofficial orbital couplings abound, but no one is talking.) Yet sexual tensions could affect crew performance and thus mission success. "It's just one more problem that can potentially cause the whole thing to come apart," says retired astronaut Norman E. Thagard.

Of course, sex is only one of the psychological components facing a space crew; isolation, loneliness, bickering and habits of colleagues can come into play. Besides space living, long-duration missions in the Antarctic, nuclear submarines, offshore drilling platforms and other remote-duty environments have provided insights. In all these locales, researchers have found, teams can become divisive, even hostile. The anger, jealousy, anxiety and depression that often evolve has, in the worst cases, compromised mission goals. "If a small number of folks are going to be forced to be together for a long period, then we've got to get pretty good at being able to pick people we know for sure won't have difficulties as a group," explains Thagard, the first American to live on board the Mir space station, where many experienced a range of untoward psychological effects.

So NASA is launching a study of behavioral issues in space in conjunction with the National Space Biomedical Research Institute, a consortium of national universities and labs. Headquartered at Baylor College of Medicine, the institute currently oversees 41 projects that attempt to find ways to combat the adverse effects of spaceflight on humans. Associate director Ronald J. White says that by next year, the NSBRI expects to add a new research team devoted to psychosocial dynamics and group behavior in space.

It's high time, some would say. The National Research Council criticized NASA's prior neglect of behavioral issues last year in a report entitled "A Strategy for Research in Space Biology and Medicine in the New Century." The "history of space exploration has seen many instances of reduced energy levels, mood changes, poor interpersonal relations, faulty decision making, and lapses in memory and attention," charged the report co-authored by Lawrence A. Palinkas of the University of California at San Diego and others. "Although these negative psychological reactions have yet to result in a disaster, this is no justification for ignoring problems that may have disastrous consequences."

Since then, NASA's decision to confront behavioral issues has surprised and pleased Palinkas, a medical anthropologist and an expert on groups in isolation. "I'm amazed," he says, adding that NASA officials, whom "I never expected to acknowledge the importance of these factors, are doing just that."

But will that touchiest of topics—sex—get the attention it deserves? "Though we are not currently supporting research on human sexuality," concedes Frank Sulzman of NASA's Life Sciences Division, "we realize that it is a difficult and sensitive area—and not something we're denying is important by any stretch of the imagination." White of the NSBRI adds: "Human sexual behavior and gender are among the key topics that should be investigated in future research."

Skeptics aren't holding their breath, however. NASA, explains psychologist and NASA adviser Robert B. Bechtel of the University of Arizona, has historically shunned the "softer" sciences in favor of technology. "They worry that the addition of unquantifiables like sexuality and psychology will somehow take away from the engineering side of spaceflight. Our task is to convince them that in today's space program—and for the future—there's room enough for both."

—*Barbara Gallagher*

BARBARA GALLAGHER, a freelance writer focusing on the space sciences, is a research associate at the Institute for Advanced Psychology in Tiburon, Calif.

PALEONTOLOGY

MAMMAL MELEE

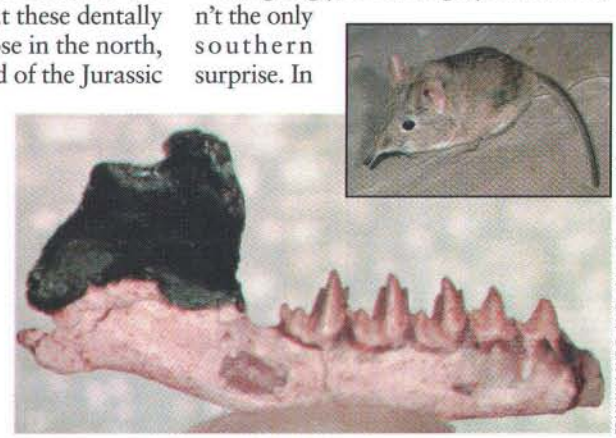
New fossils impugn leading model of early mammal origins

For decades, scholars have struggled to divine from tiny teeth and bits of bone the ancient history of mammals, and despite the paucity of the fossil record paleontologists had pieced together a plausible account. The egg-laying monotremes such as the platypus, which make up one major branch of the mammal family tree, arose in the south; the other branch, which includes the pouched marsupials and our own group, the placentals, had Northern Hemisphere roots. Placentals, in this scenario, originated in Asia, migrated to North America and later spread south. But according to recent reports in the journal *Nature* and presentations made at the annual gathering of the Society of Vertebrate Paleontology held in Denver last October, three small, shrewlike fossil mammals from Madagascar, Australia and Montana are challenging this widely held model.

Most of what scientists know about early mammals is based on dental features, because teeth are often all that remains of these tiny creatures after millions of years. Placentals, marsupials and their closest fossil relatives are characterized by so-called tribosphenic molars, in which lower and upper teeth occlude in mortar-and-pestle fashion. Until recently, the earliest tribosphenic mammals had been discovered at sites on or near the northern continents, so the prevailing view held that these dentally advanced mammals arose in the north, probably toward the end of the Jurassic period.

The fossil from northwestern Madagascar could substantially alter that picture. Researchers have unearthed from deposits that date to about 167 million years ago a jaw fragment with three teeth belonging to a mammal that they believe is tribosphenic. "It came as quite a shock," recalls André R. Wyss of the University of California at Santa Barbara. "Not only is this mammal quite a bit older than any of the previous tribosphenic mammals known—25 million years or so older—it was also in the wrong place." If Wyss and his colleagues are right about this animal, named *Ambondro mahabo*, it would imply that tribosphenic mammals originated far earlier than researchers had expected and in the south rather than the north.

Intriguingly, the Malagasy mammal isn't the only southern surprise. In



FRANK W. LANE Corbis/Frank Lane Picture Agency (shrew); RICHARD L. CIFELLI (jaw)

FOSSIL JAW found in Montana suggests that placental mammals may have originated in North America, not Asia. The 110-million-year-old jaw represents a placental named Montanalestes, *which probably looked like a shrew* (inset).

IN BRIEF

The Story of X and Y

A molecular-scale fossil dig has uncovered the evolutionary history behind the sex chromosomes. By examining the position and sequence similarity of the 19 genes still shared by both chromosomes, researchers identified four "evolutionary strata" along the X chromosome. Each layer marks a major genetic reshuffling event that occurred on Y. These rearrangements prevented recombination between the two chromosomes and ultimately led to a large X and small Y. The data, in the October 29 *Science*, suggests that the first reshuffling occurred between 240 and 320 million years ago, just after bird and mammalian ancestors separated, and the most recent was 30 to 50 million years ago, during primate evolution.

—*Diane Martindale*

Placing the Blame

Most people assume trucks are to blame. But after analyzing 5,500 fatal accidents from 1994 and 1995, Daniel F. Blower of the University of Michigan found that passenger-vehicle drivers are at fault in 70 percent of fatal crashes involving heavy trucks. In the most common type—head-on collisions—passenger-vehicle drivers crossed the center line into the truck's path eight times more often than the opposite scenario. They were also more at fault in fatal sideswipe and rear-end collisions. The study appeared in the university's June/July *UMTRI Research Review*. —*D.M.*

Truck tragedies

RON ROVTAR
FPG International

Transistor Twist

Reporting in the October 29 *Science*, IBM researchers have created a flexible transistor composed of organic and inorganic materials. The new hybrids result from a relatively cheap process: the substances crystallize out of a solution at low temperatures and "self-assemble" into layers with semiconducting properties. Being cheaper and easier to handle, the hybrids could replace the amorphous silicon now used in circuits that control active-matrix displays. —*Philip Yam*

More "In Brief" on page 26

1997 paleontologist Thomas H. Rich of the Museum of Victoria and his colleagues discovered a 115-million-year-old fossil in Australia that they believe represents a placental closely related to hedgehogs. And the team has since unearthed another specimen of the diminutive mammal, known as *Ausktribosphenos nyktos*. Rich based his placental interpretation on the animal's purportedly tribosphenic teeth, which he thinks look most like those of a placental. This would mean that placentals arrived in Australia 110 million years earlier than paleontologists thought, although an early hedgehog would fit well with molecular biologists' estimates for the origins of such specialized groups. (Most paleontologists dispute the molecular evidence, which suggests that many mammal groups have more ancient origins than those suggested by the fossil record.)

Rich's analysis, however, has met with criticism. According to Zhexi Luo of the Carnegie Museum of Natural History, *A. nyktos*'s teeth may look tribosphenic, but details of its jaw morphology—"a very important aspect that was entirely not considered by the original authors"—betray a placental interpretation. Furthermore, some researchers believe that *A. nyktos* may just be a primitive mammal, distinct from the tribosphenic mammals, that independently acquired tribosphenic-like teeth.

Considering *A. mahabo* and *A. nyktos* together, University of Oklahoma paleontologist Richard L. Cifelli suspects that convergent evolution—the independent development of similar adaptations—can better explain these and other anomalous fossils from the south. But that doesn't mean the view that placentals originated in Asia is correct. Cifelli's own efforts have yielded a surprisingly old placental from North America. This animal, dubbed *Montanalestes*, inhabited southern Montana 110 million years ago. Notably complete, the fossil is as old as any of the fossil placentals from Asia. Thus, Cifelli says, "We can no longer just go with this simplistic model that they arose in Asia and then spread into North America, because it could well have happened the other way around."

Previously, the oldest North American placentals dated to 80 million years, so why aren't there any placentals from that 30-million-year interval? Cifelli notes that if placentals did arise in North America, they either died out (perhaps outcompeted by the marsupials, which flourished then) and were replaced 30 million years later by migrants from Asia, or they persisted and their remains just haven't been discovered yet. Clearly, more fossils are needed to resolve all the issues. "Our evidence is precious little," Cifelli admits. "I think anybody who really stands up for a theory strongly is either nuts or thinks way too highly of himself." —*Kate Wong in Denver*

QUANTUM GAME THEORY

SCHRÖDINGER'S GAMES

For quantum prisoners, there may be no dilemma

The FBI has seized your computers and brought you in for questioning. They know about you and your colleague's plan to plunder the U.S. financial system with an ingenious new computer virus. Fortunately for you, the evidence is securely encrypted. But here's their offer: if you tell them the password, so they can access the evidence, they'll throw the book at Alice, your co-conspirator, to set an example, and hire you as a computer security expert. Of course, you can bet they have Alice in for questioning, too. If you both keep your traps shut, they'll have to let you go. If you both rat, you'll both do some time, but with some chance of parole, eventually.

This is the classic prisoner's dilemma: whatever Alice chooses, your best option, as a self-interested perp, is to rat on her. Unfortunately, the same logic will make her rat on you, the turncoat, and you'll both end up doing time instead of going free.

Is there any way out? Ethical considerations aside, no. The mathematics is watertight. The logic does change if you will be "playing" prisoner's dilemma many times indefinitely. Then the most profitable strategy seems to be "tit-for-tat": don't defect against a partner unless they have previously defected against you. But that's of no use in one round of the game for monumental stakes.

It turns out, as shown in a paper in the October 11 *Physical Review Letters*, that there *can* be a way out if the situation is ruled by quantum mechanics.

ANTI GRAVITY

When Good Hippos Go Bad

Imagine a sport-utility vehicle interested in mating. That frightening scenario roughly captures your typical hippopotamus in rut. Hippos are big and surprisingly fast, able to reach speeds of 25 miles per hour. Unfortunately, anything of that size and speed may do inadvertent damage when in pursuit of an amorous adventure. Thus did a tragic death recently befall one Jean Ducuing, the director of a zoo near Bordeaux. Ducuing was killed by a charging hippo that may have been seeking intimacy with, or dominance over, nearby farm equipment.

The sex life of the hippo is far stranger than this incident illustrates. For one thing, hippos in the wild not only have sex, they host it. Back in 1994, researchers publishing in the *Canadian Journal of Zoology* announced the amazing finding of a species of leech, *Placobdelloides jaegerskioeldi,* for which hippos are a secret love nest. In the researchers' own words: "Evidence suggests that mating in *P. jaegerskioeldi* is restricted to the rectum of the hippopotamus." (Restricted being the operative word.)

The scientists based their conclusion on the examination of 53 dead hippos, probably because rectal exams on live hippos are currently discouraged by all major research university health insurance plans. The only place on or in the hippos where sexually mature leeches were accompanied by spermatophores, or packages of sperm, was the rectum. Proof once again that anything Hollywood comes up with in its *Alien* movies or assorted rip-offs pales in comparison to the bizarre variations of the life cycle that evolution has patiently produced here on earth.

Fortunately for your average hippo, the immense creature has notoriously bad eyesight, which may help it maintain a sanguine attitude toward the foul play going on at its other end. Those feeble peepers might be at least partially responsible for the fatal charge that did in Ducuing. A poor self-image may also be a factor. How else to explain the fact that Komir, the French zoo's seven-year-old, two-ton male, apparently thought he was seeing either a female hippo or a competitor when in fact he was myopically gazing at a new tractor, which he decided to chase.

A key discovery that the ensuing tragedy made possible was that electrified fences are not sufficient deterrents to an inflamed hippo. Ducuing just happened to be at the wrong place at the very worst possible time, an innocent bicycler who was riding near the tractor when the hippo went after it. The *International Herald Tribune* actually quoted a zoo spokesperson as saying, "It was a crime of passion." Another zoo employee went on record with, "Komir had always been jealous of that tractor." Taking a page from local townspeople's handling of Frankenstein's monster, zoo workers used pitchforks to drive the hippo back into its enclosure.

Ironically, Ducuing had enjoyed a long and amicable relationship with Komir. The zoo director had trained the animal and had been photographed trustingly putting his head inside the hippo's gargantuan open jaws. Two tons of motivated meat, however, outweighs the fellowship of old friends.

This magazine's Carol Ezzell recently had her own near-hippo experience. Ezzell, we are quite happy to report, survived. On assignment in Zimbabwe (see page 26), Ezzell was in a Land Rover about 15 feet from a seemingly docile, elderly male hippo when, provoked by Ezzell's guide, the beast suddenly roared and ran straight toward her. "And he moved fast," she testifies. "He covered the distance in a flash." That hippo, however, allowed Ezzell to return to us by emulating the leeches that most likely infest him. He turned tail. —*Steve Mirsky*

MICHAEL CRAWFORD

The essence of quantum mechanics, and how it can help, is embodied by another hapless inmate: Schrödinger's cat. In the infamous thought experiment the cat becomes a superposition of alive and dead inside its infernal box, and only when a measurement is made—someone opening the box and looking in—does it become wholly alive or dead.

Similarly, one can conceive of a superposition of defecting and not defecting. Physicist Martin Wilkens of the University of Potsdam in Germany and his coworkers show how to extend the prisoner's dilemma to a theoretical quantum system. Each prisoner encodes his choice (some superposition of defect and cooperate) onto a simple quantum element inside a device. The device combines the two elements, performs a measurement and announces a definite choice (either defect or cooperate) for each prisoner.

When the device is configured to take the most advantage of another quantum effect—when it "maximally entangles" the two choices—the dilemma vanishes: among the new quantum choices available is one that will let each prisoner reap the benefit of keeping quiet. Neither player has a motive for deviating from this preferred quantum strategy; doing so would lower his or her expected payoff. The entanglement links the announced choices, so that you and Alice can cooperate without risk (or temptation) of unilateral defection.

Another quantum variant of game theory was studied by David A. Meyer of the University of California at San Diego: a game called "penny flipover." A coin inside a box begins heads-up, and the players (called Picard and Q, by Meyer) take turns flipping it over, or not, without seeing which side is up; first Q, then P, and finally Q again. If the coin finishes heads up, Q wins. With a classical penny, each player does best by flipping at random, winning half the time. But if Q can exploit quantum superpositions, he can win every time. First he puts the coin into an equal superposition of heads and tails. This state is unchanged even if P flips the coin. On his final turn, Q returns the superposition back to purely heads!

The importance of such results is not for avoiding the clutches of quantum G-men or con men. Instead they provide an instance of how quantum principles alter information processing. Furthermore, the coin flipper is a prototype error-correction system—negating the effects of random "errors" introduced by player P's move. —*Graham P. Collins*

Going the Distance

Every year about 14 million Americans move to another county, and about 840,000 legal immigrants enter the country. These two groups—defined as long-distance movers—are the subject of this map. The 26 million or so Americans who move within their counties every year are not included.

The majority of long-distance movers are people in their 20s, who migrate for career reasons. They tend to be single, better educated than average and are equally divided among men and women. Non-Hispanic whites and African-Americans are more likely to move long distances than Hispanics are. People age 65 and older comprise less than 3 percent of all long-distance movers.

This pattern is not new. Americans have been moving west for centuries and out of the prairie states for decades. They have moved south in large numbers since the 1960s as industry left the Rust Belt. The South has gained because of lower labor costs and the rise of light industry, such as electronics, that depends on trucking rather than rail transportation. Tax incentives, the spread of air-conditioning and the success of the civil-rights movement also contributed to the rise of the South. A major exception is a band of counties with a high concentration of African-Americans, stretching from Louisiana to Virginia, that had a net outflow of migrants.

One obvious effect of migration is on age distribution. For example, in Erie County, New York (Buffalo), an area with a substantial outflow of migrants, 16 percent of residents are 65 and older; in Clark County, Nevada (Las Vegas), an area of very high inflow, 11 percent are in this group. Far more dramatic is the effect of migration on the mix of newcomers and natives, which presumably influences the rate at which local institutions and attitudes change. In Pennsylvania, four out of five residents are natives of the state, but in Nevada, the proportion is one out of five.

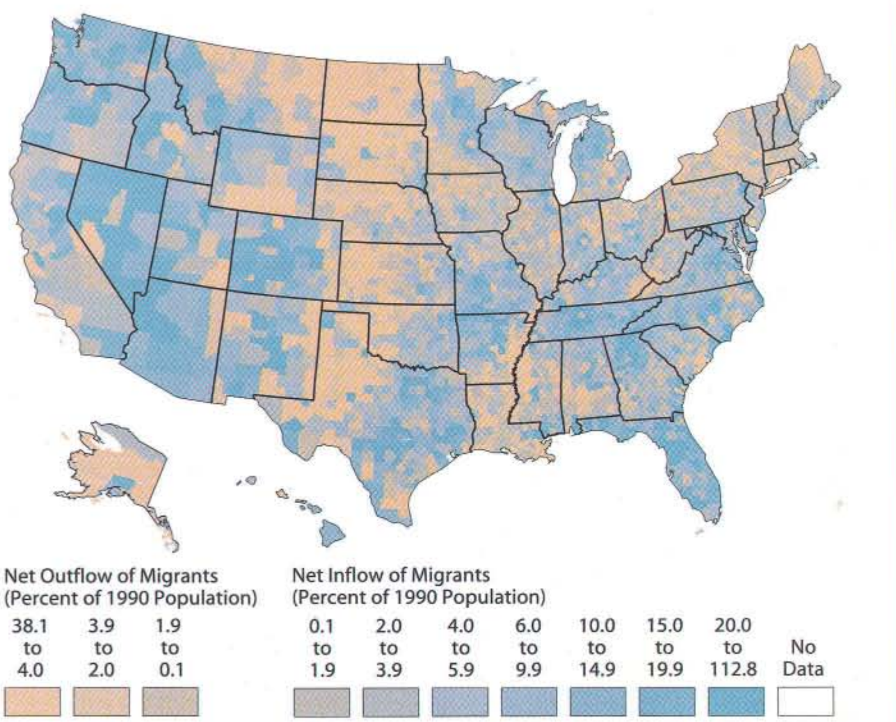
Migration also influences social policy attitudes. Southern whites who moved to the North in the 1980s and early 1990s tended, as a group, to adopt somewhat more liberal attitudes to such policies as busing and federal spending, whereas Northern whites who moved to the South tended to become somewhat more conservative. Migration seems to have had little effect on regional differences in church membership. Apparently, migrants tend to conform to the religious climate of their new home. There is an old theory that migration, because it usually loosens the bonds of family and community, leads to an increase in suicide, divorce and crime. There is some suggestive evidence for this: the recent distribution of migrants in the U.S. roughly parallels the incidence of suicide and divorce, and a rapid influx of migrants into metropolitan areas is associated with higher crime rates.

Of the 50 largest counties, 26 had a net loss of migrants in 1990 through 1998, but of these, 15 did not experience a population loss (the loss was outweighed by an excess of births over deaths). Continuing a long-apparent trend, the central counties of metropolitan areas had a net loss of migrants, while suburban counties had a net gain. Nonmetropolitan counties also had a net gain but far less than that of the suburbs. Movers from abroad concentrated in the bigger counties, with 41 percent going to Los Angeles, Chicago and the five counties of New York City.

The proportion of long-distance movers reached a post–World War II peak in 1967–1968 of 7.7 percent but has since fallen and was 6 percent in 1996–1997. Among the factors that may be behind the decline are the growing proportion of two-career families, who find long-distance moving difficult; the decline in the divorce rate in recent years; the growth in home ownership; the shift toward delayed marriage over the past 30 years and a drop in the 20-something population. Americans are far more likely than western Europeans to move long distances and about as equally likely to do so as Canadians and Australians.

—Rodger Doyle (rdoyle2@aol.com)

Effect of Migration on County Populations, 1990–1998



SOURCE: U.S. Bureau of the Census. Data include domestic migrants and legal immigrants but exclude American citizens returning from abroad.

RODGER DOYLE

PROFILE

Setting the Course for the Nation's Health

How Harold E. Varmus, former director of the National Institutes of Health, went from science to administration—and boosted medical research

When Harold E. Varmus went to Washington, D.C., in 1993 to become director of the National Institutes of Health (NIH), the physician and professor of microbiology had no experience of managing anything larger than a 25-person laboratory at the University of California at San Francisco. The constellation of federal research institutes (whose campus is actually in Bethesda, Md.) had at the time a budget of $10.3 billion.

By the time he stepped down last month to become president of Memorial Sloan-Kettering Cancer Center in New York City, the NIH's budget had reached $15.6 billion, a remarkable rate of growth at a time when the political drumbeat has been all for smaller government. Congress's largesse toward the agency is to a considerable extent the result of Varmus's ability to cultivate good relationships with members of Congress on both sides of the partisan divide. That skill, observers agree, has been enhanced by his status as a Nobel laureate: he shared the most coveted prize in science with J. Michael Bishop in 1989 for their work on oncogenes in retroviruses.

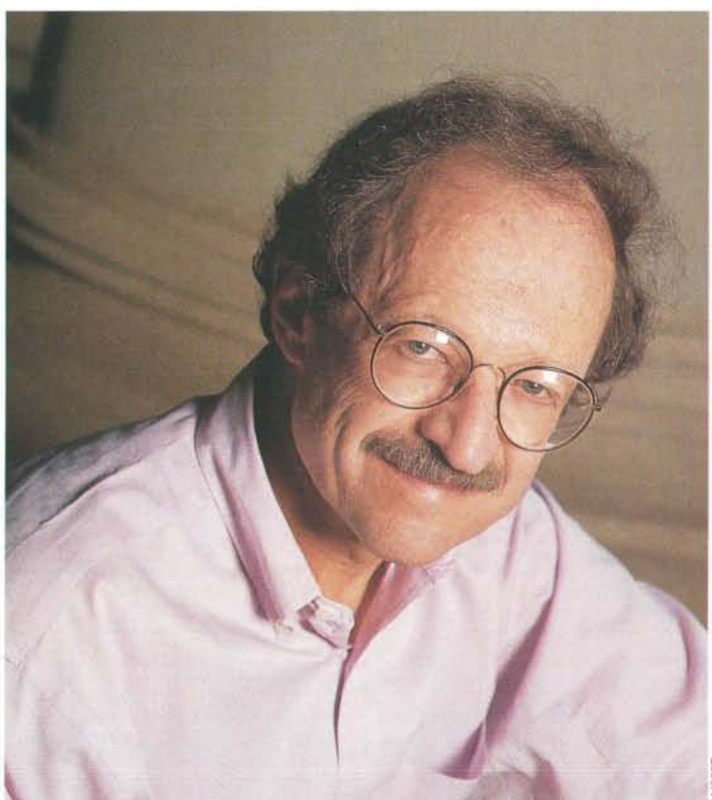
Varmus was able to pay competitive salaries to turn around declining morale at the agency and recruit leading investigators to become part-time administrators. Clinical research, which was in decline, has picked up, and a construction boom is under way. "He is the first director of the NIH of world-class scientific stature, and it has made an enormous difference," comments Robert A. Weinberg of the Massachusetts Institute of Technology, a researcher who, like Varmus, studies genes involved in cancer.

Varmus has not avoided controversy—which would be impossible in a job that is inherently more political than scientific. Harold Freeman, president of Harlem's North General Hospital and chair of the president's cancer panel, says that despite Varmus's "superb" performance, the agency—and society at large—is still not doing enough to convert discoveries to delivery of health care to "real people in real neighborhoods." The NIH was roundly criticized a year ago in a report by the Institute of Medicine, which charged that it had neither a strategic plan nor an adequate budget to coordinate research on cancer among ethnic minorities. Varmus says he is "as troubled as anybody" by health disparities in minority communities. But he has resisted a congressional move to elevate the status of the NIH's Office of Research on Minority Health to make it a National Center: the NIH already has too many centers, he maintains.

He has also recently alarmed publishers of academic journals by pushing a plan for the NIH to establish an Internet-based distribution system for unreviewed scientific papers, to disseminate data more quickly and reduce costs for libraries. The plan, with a changed title and a more limited scope than when Varmus first proposed it, debuts this month under the name of PubMed Central. The system will distribute peer-reviewed articles contributed by existing journals and, separately, some nonpeer-reviewed articles, but even these will undergo some screening.

Varmus, 60, has by all accounts taken well to the pressures of a bureaucratic high-wire balancing act. Interviewed on a perfect fall day shortly after the announcement of his impending departure, he seemed to be in a notably cheerful mood, tieless and fast-moving as usual. When he leaves his seat to fetch a document or to check an incoming e-mail, Varmus seems to bound more than walk, a consequence, perhaps, of his athleticism. While at the NIH, he cycled 12 miles to work most days, often breaking the journey with a dawn row.

Varmus's intellectual history is unusual: although his father was a physician, he took a master's degree in English literature at Harvard University before deciding to try medical school. His experiences there impressed him with the power of science to provide some rational treatments, such as supplying a hormone to a patient whose body cannot make the substance. But he was struck more by how rarely scientific principles could



KATHERINE LAMBERT

SCIENTIFIC RENOWN *and consensus-building talents enabled Harold E. Varmus to reinvigorate the nation's premier biomedical research institution despite his being the focus of controversy.*

be applied, given the existing state of knowledge.

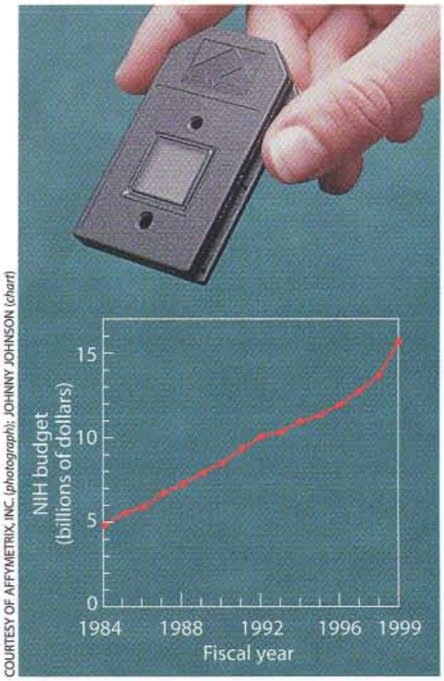
During his tenure at the NIH, Varmus has grappled with disease advocates who demand that the NIH disburse funds in proportion to the death and disability the conditions cause. He acknowledges the need for accountability but asserts that his position obligates him to channel funds to where scientific opportunities lie: it is often almost impossible to say which patients might benefit from a given type of research, he maintains. In an attempt to achieve a broader consensus, Varmus has initiated efforts to refine the definitions the NIH uses to classify expenditures and has stepped up community participation by creating a new Council of Public Representatives. He has also brought in outside experts to examine the NIH's grant review process, long a source of discontent among researchers, who often see it as unresponsive to new ideas. "The constituency that cares about what we do has very frequently been invited here to be part of the public process," Varmus explains.

He seems enthusiastic about the challenges of leadership. Yet the burgeoning number of NIH centers and institutes have made it difficult for him to provide suitable oversight, he asserts. Hence his recent suggestion that the agency, which now comprises some 25 separate administrative institutes or centers, most with their own congressionally established budget lines, should at some point be reorganized into six mega-institutes. He believes that bigger institutes are frequently more innovative than the smaller wannabes and calculates that if the number of the NIH's components continues to grow as it has over the past 30 years, it will include more than 50 parts by 2040. He realizes that because neither disease advocates nor institute directors are likely to favor his solution, it is politically unrealistic in the short term. But he hopes that at some point a national commission will grapple with the problem.

Varmus insists that he has enjoyed his stint as director, although he thinks his successor ought to have a thick skin to withstand the inevitable attacks. And he admits that he is looking forward to being more closely involved in directing research, a function filled by individual institute heads at the NIH. (He also notes ruefully that the new director should probably be willing to accept a substantial drop in salary, with no honoraria to ease the transition.)

Like many other biomedical researchers, Varmus believes the coming decade will start to see many more health benefits flowing from the rapid advances in molecular-level understanding of disease. He acknowledges that gene therapy is taking longer to advance than investigators—and the public—expected. But he is certain that more traditional pharmaceutical development will also benefit enormously from the Human Genome Project and other areas where the NIH has made major investments.

He is particularly impressed with the



COURTESY OF AFFYMETRIX, INC. (photograph); JOHNNY JOHNSON (chart)

HEALTHY GROWTH dominates the budget of the National Institutes of Health, where Varmus pushed technologies such as GeneChip probes (above).

potential of rapid genetic screening technologies for detecting variations in individuals' DNA that might hold prognostic and diagnostic significance. Better classification of diseases often leads to more favorable outcomes from treatments, because doctors then have a better idea which, if any, are likely to be effective. Bone marrow transplantation, whose value in breast cancer has been called into question, might be effective for some such patients, he suggests. But Varmus cautions that society will have to provide protections against discrimination and loss of privacy before screening technology can deliver on its potential. If a genetic predisposition to a condition is sufficient for someone to lose affordable health insurance, patients will be reluctant to embrace the new technologies.

Scientists, likewise, will have to adapt to a new way of doing business. Many researchers have become "addicted to a cottage-industry model" for biomedical research. Varmus has a strong belief that biomedicine now needs information technologists to develop databases and engineers to develop new tools as much as it needs traditional laboratories. "The institute directors and I have reached a consensus that technology development is not to be left to industry but is something we need to be involved with fairly heavily," he explains. The NIH supports research in companies as well as in universities and on its own campus, but Varmus the scientist does have significant anxiety about spreading commercialism in research. Institutions looking for profits are, he says, becoming increasingly possessive about their discoveries and are placing ever more onerous restrictions on scientists who want to exchange research tools such as transgenic animals, clones and cell lines, including those developed with federal funding.

Part of the problem, he speculates, might be a growing tendency for institutions to patent inventions at a very early stage, long before anything practical has been created. "I am not always convinced they should be patented in the way they are," he remarks. Yet he acknowledges the need to preserve incentives to encourage clinicians to develop, for example, new treatment regimens.

Varmus will have plenty of opportunity to wrestle with such issues at Sloan-Kettering. Observers familiar with cancer research say that although that institution has a strong basic research program, it is less effective at organizing cutting-edge clinical research. Varmus hopes to help spur a biotech renaissance on the Queens waterfront, across the East River from his new institution in Manhattan and several other preeminent research centers. He envisages ferries shuttling collaborators from place to place across the water. Yet expanding research on treatments will not be straightforward: most patients are insured by health-maintenance organizations, which are dedicated to reducing costs. Varmus's scientific clout and instinct for seeking consensus might be just what is needed to persuade industry, insurers and scientists to pull together.

—*Tim Beardsley in Washington, D.C.*

AVIATION

SELF-CONTROL IN THE SKIES

An onboard device for flying closer together more safely

It shouldn't have happened. This past summer over China, two Boeing 747s were flying toward each another along the same airway but separated vertically by a safe and wholesome 2,000 feet. As the jets drew within spitting distance, however, the Traffic Alert and Collision Avoidance System (TCAS) installed in the lower jet began its auditory warning to the pilot, "Climb! Climb!" And so the pilot did—to within just a few hundred feet of the oncoming airliner's belly. Only by that narrow margin did 422 passengers and crew miss going down as the worst midair collision in history.

Some 3,000 TCAS units are on passenger and cargo aircraft. Developed in the 1980s in response to several midair collisions, TCAS works by interrogating the altitude-reporting radar transponder of other aircraft, displaying the altitude of traffic nearby and issuing an auditory warning. There's no doubt that it works: TCAS has reduced the incidence of near-collisions in the U.S. from 20 annually to four, and so far engineers believe the erroneous climb warning in the China incident to be a rare anomaly. Still, common versions of TCAS are most accurate within 14 miles—less than a minute's notice for airliners on a head-on trajectory.

Now, though, the replacement is on its way—a technological leap above TCAS that could not only keep planes at safer distances but also relieve the rampant congestion in the air traffic system. In keeping with the unwieldy, unpronounceable acronyms traditional to aviation instrumentation, it's called ADS-B, for Automatic Dependent Surveillance-Broadcast, and has been jointly financed by the airlines and the Federal Aviation Administration to the tune of $50 million. Coupled with Global Positioning System (GPS) technology, ADS-B can display and identify in real time aircraft traffic that is up to hundreds of miles away. Not only can it give the position of traffic relative to the host aircraft, but it also shows that traffic's velocity and intent—that's the "surveillance" part of its acronym. It's "automatic" because, unlike the radar transponder typically used on all aircraft, including those with TCAS, it needs no interrogation to elicit a response. It's "dependent" because instead of ground-based equipment it relies on onboard electronics. The "broadcast" comes from its continuous transmissions to all.

The information in ADS-B makes it much more than just the replacement for TCAS. It's also the cornerstone of Free Flight, the much-touted air traffic–control system of the future that is supposed to allow pilots greater leeway in choosing their routes while maintaining safe separation. In the first wide-scale test of the concept and its technology last July, the FAA gathered 24 ADS-B-equipped aircraft of various sizes (everything from a Boeing 757 and several 727s to a navy P-3 Orion and a single-engine Piper Cherokee) and put them through the paces above a test facility in Wilmington, Ohio.

The efficiency surprised even the participants. "The best measure of success: we planned for 96 approaches; we accomplished 217," says the FAA's Paul Fontaine, project leader for the Wilmington test. The pilots found that the display could tell them exactly how much the aircraft ahead of them was speeding up or slowing down and thus allow them to adjust their own speed accordingly. For the first time, they could maintain the precise minimum separation intervals prescribed by regulations. Under the old system, pilots know only what controllers tell them: it's difficult to judge relative motion even in a clear blue sky and nearly impossible to do so at night. As a result, pilots and controllers prefer to pad their separation. "They don't always maintain the minimum of three miles on final; they can get strung out," Fontaine explains. Just flying up to such minimum standards within the airspace system is going to make the system more efficient, he points out.

And unlike TCAS and other radar-based systems, ADS-B (with GPS correction) works on the ground, which will help reduce the threat of runway incursions, and in crowded airspace close to the ground. Ironically, in highly congested airspace pilots turn off the radar transponders that TCAS relies on; the dense number of returns overloads controllers' radar screens.

The Wilmington test was so successful

CARGO AIRLINE ASSOCIATION

JACQUES M. CHENET *Corbis*

***RUNWAY CONGESTION** could be alleviated through the ADS-B system, which tracks the location and direction of nearby traffic in a cockpit display* (inset). *The white triangle is the viewer's aircraft; other planes are in blue and yellow.*

that the FAA wants to proceed with a long-term trial run starting in 2000, equipping all the jets and the hub airport of a cargo carrier like United Parcel Service. The technology may be ready for mass deployment by 2004. And not a moment too soon: FAA forecasts indicate that air traffic will grow between 3 and 5 percent annually for the next 15 years. Meanwhile delays for the first eight months of 1999 were up nearly 20 percent over the previous year.

"The fact is, the radar-based [air traffic-control] system as we know it is under a lot of strain," says Craig Bowers, a UPS flight-systems official. "There's only so much airspace and so many ramps and gates. We have to operate the system more efficiently if we want to solve any of these delay problems." And they have to keep improving the technology if they want to prevent those crowded skies from turning deadly, as they nearly did over China. —*Phil Scott*

PHIL SCOTT, based in New York City, is a frequent contributor specializing in aviation issues.

CIVIL ENGINEERING

WINDS OF CHANGE

Can skyscrapers withstand stronger hurricanes?

Last year's hurricane season, with Floyd unleashing 155-mile-per-hour winds, heightened fears that the U.S. has entered a period of increased storm activity along the Gulf and Atlantic coasts. With Hurricane Andrew still a potent memory, questions about public safety, particularly if a hurricane should strike a major urban center, have intensified. In one doomsday scenario, a skyscraper in a densely populated area like New York City would collapse, destroying not only itself but the nearby buildings as well. Experts agree that such a catastrophe is highly unlikely, but recent research has highlighted other potential dangers.

Although many scientists claim that the current crop of hurricanes is within statistical norms (following a lull in the 1970s and 1980s), others assert that global warming might be a factor. According to one theory, higher temperatures at the ocean surface will spur an increase in the severity of the strongest tropical storms. In a recent computer simulation of western Pacific storms by researchers with the National Oceanic and Atmospheric Administration, a temperature rise of just four degrees Fahrenheit led to wind speeds that were up to 12 percent higher. Because the wind force is directly related to the square of the speed, even slight increases in wind velocities could lead to significantly more damage.

Of course, architects and engineers could erect skyscrapers that were virtually invincible by simply adding enough steel and concrete. But the cost would be prohibitive, so a probabilistic approach is used. Specifically, buildings are constructed to be strong enough that they will not suffer any damage from a "design wind," usually chosen to be a storm that would statistically occur only once every 50 years or so.

With stronger winds, the skyscraper might experience some minor strain—cracking in the interior walls, for instance—but no serious structural damage. Such loss would not occur unless the storm was at least 50 percent stronger than the design wind, according to R. Shankar Nair, chairman of the Council on Tall Buildings and Urban Habitat at Lehigh University. And even then, high-rises have additional reserve capacity. "A building can take about twice its design load without actually collapsing," Nair asserts.

But there are other concerns. Strong winds exert extreme pressures on a building (high on the windward face and low on the leeward side), potentially causing windows to be blown into or out of the structure. Another threat is flying objects, including loose branches, signs, gravel and other debris, that could strike the windows. In August 1983 Hurricane Alicia, with sustained winds of 60 miles per hour, shattered hundreds of windows from high-rises in the downtown Houston area.

Shattered glass is merely the beginning. "Once a lot of rain gets into an office building, it can do an awful amount of damage in a short period," notes Alan G. Davenport, director of the Boundary Layer Wind Tunnel Laboratory at the University of Western Ontario. And wind rushing through broken windows might inflate the structure, eventually tearing it apart from the inside out. Consequently, many new buildings in hurricane-prone regions have sturdier window systems of impact-resistant laminated glass, similar to that used in automobile windshields.

Such technological advances are also

COURTESY OF THE INSTITUTE FOR DISASTER RESEARCH, TEXAS TECH UNIVERSITY

SHATTERED GLASS rained on Houston when Hurricane Alicia struck in 1983.

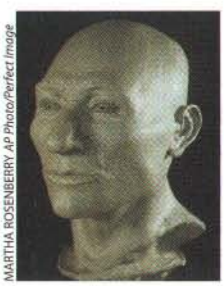
In Brief, *continued from page 18*

Perfect-Pitch Men

Mozart's gift of perfect, or absolute, pitch may not be so rare. The mysterious ability to identify a note without referring to another note has been thought to occur in fewer than one in 10,000 people. But at the November meeting of the Acoustical Society of America, Diana Deutsch of the University of California at San Diego revealed that perfect pitch may be the norm among native speakers of tonal languages. She studied 22 speakers of Mandarin and Vietnamese who had little or no musical training and found they possessed highly accurate perfect pitch, as reflected in their enunciation. About one third of the world's population speaks a tonal language. —P.Y.

Origin of the Kennewick Skeleton

Found along the Columbia River in Washington State, the 9,300-year-old Kennewick Man—whose facial reconstruction made him look like the actor Patrick Stewart—is associated with Polynesians (by 64 percent) and the Ainu of Japan (24 percent) and not with American Indians or, as originally thought, Europeans. Joseph F. Powell and Jerome C. Rose, under the auspices of the Department of the Interior, took virtual measurements from a three-dimensional computer model, re-created from many algae-stained bone fragments. They compared the bone and cranial measurements with a database on a wide range of ethnic groups to draw their conclusions. —D.M.



MARTHA ROSENBERRY AP Photo/Perfect Image

Asian heritage

Pollution Data Flawed

Much environmental data on pollutants may be unreliable, say David L. Lewis of the University of Georgia and his colleagues in the October 28 *Nature*. Pollutants, such as herbicides and insecticides, are chiral—composed of enantiomers, or molecules that come in mirror images of each other. Plants died when exposed to one form of the herbicide dichlorprop but not in the presence of its mirror twin. The survival of the plant actually depended on whether soil microbes preferentially degraded a particular enantiomer. The preference, in turn, depended on soil conditions, which determined which microbial populations were present. —D.M.

being retrofitted in existing structures, which raises a question regarding the safety of older skyscrapers. The Empire State Building, for example, was reportedly designed to withstand a wind pressure of 20 pounds per square foot; the current code in New York City calls for twice that amount. Ironically, though, older structures may actually be safer than newer ones because they were designed with greater margins for error. Also, earlier structures typically have heavy stone, brick or concrete exteriors, compared with the lightweight metal and glass curtain walls of many modern skyscrapers.

The greater danger, experts say, is in so-called nonengineered buildings (houses and other low-rise dwellings), which can be torn off their foundations by a strong hurricane, such as 1992's Andrew. Fortunately, the full brunt of Andrew missed Miami, and the skyscrapers there suffered relatively minor damage. But the houses in the surrounding areas were devastated, contributing to estimated losses of $25 billion.

—Alden M. Hayashi

CONSERVATION

JUMBO TROUBLE

Is it time to cull some elephant populations in southern Africa and sell the ivory?

One of the first things a visitor to Hwange National Park in northwest Zimbabwe notices is the trees—or rather the paucity thereof. Everywhere one looks, young saplings and middling trees have been bent back, snapped off and generally broken down, their dry branches hanging at odd angles. Some have deep pits at their bases that expose their spindly roots to the surface.

Has Hwange been hit by a storm? No, it's the work of elephants—lots of elephants.

For more than a decade now, environmentalists' concerns over the African elephant have centered on the damage that poachers wreaked on the species as they slaughtered animals for their ivory tusks. In 1988 elephant maven Cynthia Moss of the African Wildlife Foundation estimated that 80,000 were being killed annually, a rate that had slashed African elephant populations by half since 1979. Most of the slaughter occurred in eastern and central Africa.

But elephant herds in southern Africa have increased since the Convention on the International Trade in Endangered Species (CITES) enacted a ban on the sale of ivory in 1989. Indeed, wildlife managers are beginning to complain that elephant numbers have increased in some areas to the point that the beasts' taste for tree branches and roots is destroying the environment for other species. At Kruger National Park in the Republic of South Africa, things have reached the point that biologists are testing the efficacy of a contraceptive vaccine in a group of elephant cows. And in November the South African Department of Environmental Affairs and Tourism announced that it would petition CITES to downgrade its listing of African elephants in South Africa from Appendix I, which prohibits trade, to Appendix II, which would open the door to the export of ivory.

Noncontroversial censuses of African elephants in various regions of southern Africa are hard to come by, but a 1999 survey found that Kruger National Park holds 9,000 elephants even though its sustainable carrying capacity is only 7,000. In 1995 the Zimbabwe government reported a total count of 66,631 elephants—more than twice what it considered the appropriate capacity for the country.

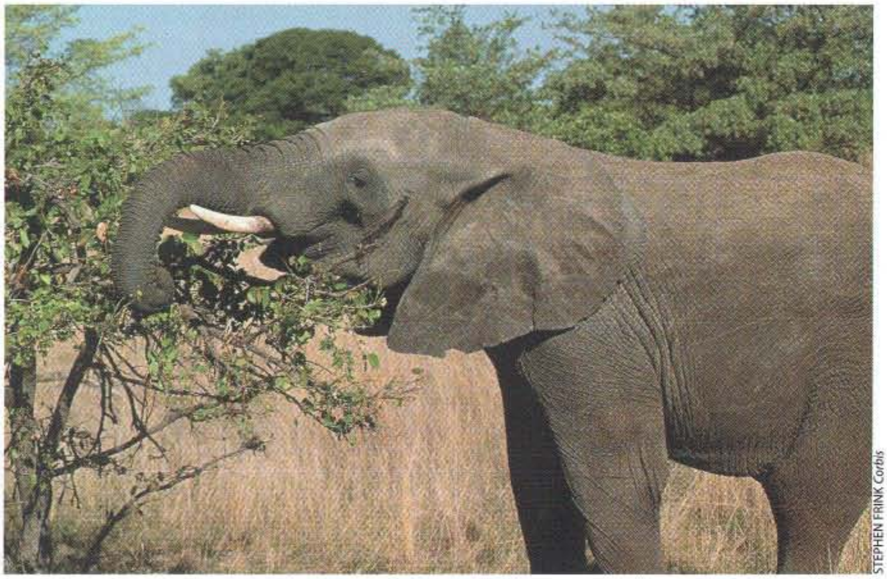
The Zimbabwean elephants are distributed in four main ranges, with the majority in Hwange National Park. Richard G. Ruggiero, program officer for the U.S. Fish and Wildlife Service's African Elephant Conservation Fund, says "most reasonable people" would conclude that the elephant population in Hwange is out of hand. But he adds that the problem is not too many elephants, it's not enough habitat.

Before colonization, Hwange was "a dry wasteland that didn't support much wildlife," Ruggiero recounts. It became a national park because it had low agricultural potential. During the dry season, most of the watering holes in the park are fed by man-made pumps. "It's a system that was created by humans, and it needs to be managed by humans," he asserts.

Whether contraceptive vaccines are the best answer is still up in the air, though, according to Ruggiero. The U.S. Fish and Wildlife Service provides more than half of the funding for the contraceptive experiment at Kruger (the

Humane Society of the United States manages the project). Starting at the end of 1996, scientists there injected 21 nonpregnant elephant cows with a vaccine made from the outer coating of egg cells taken from pigs. It is supposed to work by eliciting an immune response in the cows against their own eggs that will prevent them from becoming pregnant. But the first round of data has shown the vaccine to be only roughly 60 percent effective, a problem the researchers predict they can overcome by giving booster inoculations every 10 months. Nevertheless, Ruggiero suggests that the approach might work best with small numbers of elephants in a relatively confined area.

Besides, it may not be politically salable, remarks Lloyd Sithole, consul at Zimbabwe's embassy to the U.S. A contraceptive approach "is not popular," he warns. "People believe wildlife should be culled periodically to help people" through the sale of meat, hides and ivory. "If wildlife doesn't benefit the people, they will want to use the land for other purposes." Sithole says his country has not yet made any decisions either to conduct contraceptive tests among its elephant herds or to begin culling.



STEPHEN FRINK Corbis

AFRICAN ELEPHANT chows down on a tree in Zimbabwe. In some parts of southern Africa, increasing numbers of elephants are ruining the ecosystem for other species.

Last April, Botswana, Namibia and Zimbabwe received approval from CITES to sell government stockpiles of tusks that had been collected from natural elephant deaths since the trade ban on ivory was implemented. Zimbabwe sold 20 tons, Namibia auctioned more than 12 tons and Botswana sold nearly 18 tons. All three governments agreed to use the proceeds—the total of which they are keeping confidential—for conservation efforts. *—Carol Ezzell in Zimbabwe*

CYBER VIEW

Making Money the New-Fashioned Way

If you read the business press on the subject of stocks, finance and the Internet, you will come away with two strong impressions. First, day trading is very, very dangerous, and the Internet is turning investing into a high-stakes casino. Second, everyone's getting rich on Internet bubble stocks, and they are going to crash soon but maybe not yet. There is, however, a subtler, more interesting question: Is the Internet democratizing finance?

Certainly the past couple of decades have created a record number of millionaires and even billionaires. But, as studies show, the gap between rich and poor has widened over those decades, and the wealth has become more concentrated in the hands of a smaller percentage of people. On the other hand, stock ownership has increased its penetration into the general public. According to a CNBC survey, some 70 million Americans now own stocks. The bug is catching internationally: everyone I know in Britain, where as recently as a generation ago only the very wealthiest few owned shares, is calling me up to ask how to trade in the U.S. (Alarmists take note: if ever you wanted evidence that the bubble was about to pop, this may be it.)

For anyone who traded stocks in the old days of $250 commissions and utter dependence on a broker for access to even the barest information about companies (unless you were willing to write scads of letters requesting annual reports), the Net today is an astounding bazaar of information and $8 trades. For free, you can look up a company, its fundamentals, its earnings history and its filings with the Securities and Exchange Commission; peruse relevant business news stories; and find out whether it's doing anything to arouse ire—all in little more time than it takes a television analyst to say disparagingly, "It's a *value* stock." Information that used to be kept by professionals under lock and key—analysts' earnings estimates and stock preferences of company officials—can now be had for free.

All these facts at the fingertips, though, may not be helping the individual investor much. A recent study out of the University of California at Davis found that experienced investors performed worse when they moved to on-line from telephone brokering: they made more frequent, riskier and less successful trades. The study attributed the change to overconfidence—exacerbated by the investors' belief that they were the architects of their own financial destiny. I'd suggest there's also a sense of secret sin about on-line trading (which I greatly prefer myself) that isn't there when you have to explain your choices to another human being before they're enacted. If you fail, no one has to know.

DAVID SUTER

Gavin Starks, a managing director for Internet start-up Tornado Productions who trades on-line from England, comments on the strange sensation of being up—or down—thousands of dollars because of a single click: "Over the last year I've probably quadrupled the amount I actually put in, and seeing the number on the screen is quite surreal because it doesn't relate to anything in the tangible world." This mirage is, he adds, especially true because "I'm invested in companies that are pretty much vapor." This surreality is complemented by the fact that the Net-fueled response to good or bad news on a company is now so fast. Some selling off after bad news is reasonable, but some of the recent price pops are nothing more than a popularity vote, something the TV networks made clear when they ran call-in polls on whether Martha Stewart Living or the World Wrestling Federation would close higher on the first day of their initial public offerings (IPOs). Who needs a broker when investors can sell themselves on buying a risky IPO stock? (Most high-flying IPO stocks sell a few weeks later at lower prices than their first-day close.)

The recent flap over Red Hat IPO shares showed just how much the market still keeps its riches for its nearest and dearest. Red Hat is the best-known distributor of the free operating system Linux, and when the company went public many Linux hackers were offered IPO shares. Trouble was, few were able to pass the test applied by the underwriting broker that is supposed to ensure that inexperienced investors do not risk their only assets on an unproved equity. The law made more sense before the Internet and its low-cost trades: shut out of IPOs, relatively penniless but knowledgeable hackers are still free to buy the same shares on the open market—for three times the initial price. As C. Scott Ananian, one of the lucky ones who got shares, wrote in the e-zine *Salon,* "We had no power in this world; no one cared to listen to what we had to say."

Even experienced brokers think individual investors affect the market more now than they did in the past, making prices less clearly predictable. More immediately, Starks says on his occasional forays into day trading, you can see the U.S. wake up and come on-line, then a visible lull during lunchtime and a second peak midafternoon. Even more interesting will be the planned move to extended-hours trading and next, inevitably, trading 24/7. Those changes will tip the balance toward institutional investors, who have the staff to monitor the markets in continual shifts; individual investors would not want to hold something short-term that might crash while they were asleep.

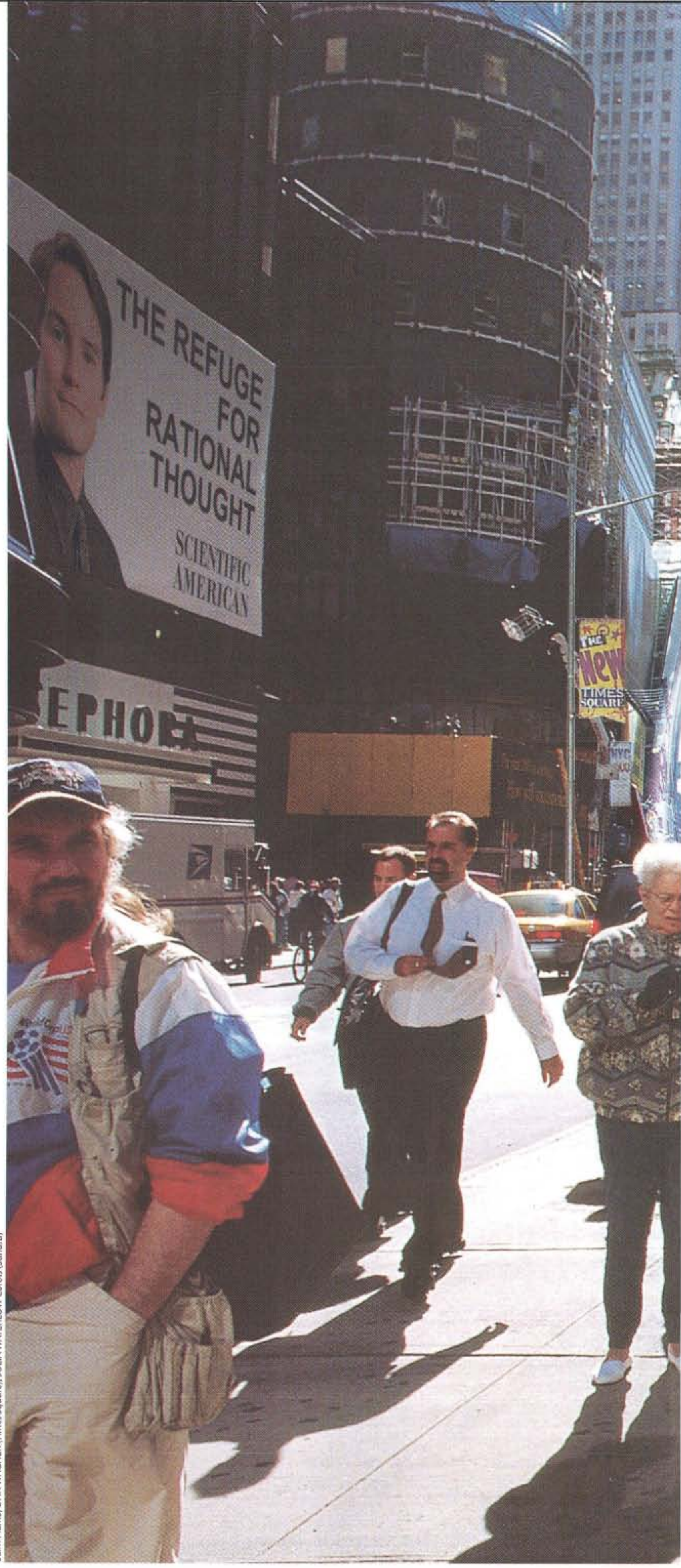
When you think about it, it's obvious that financial services would be one of the first big business areas to feel the effects of the Internet. Forget all those big, heavy books you can order on-line. The heaviest things financiers trade are engraved pieces of paper; the most common things they trade are information and numbers, which are perfect for transmission across the Internet. The reason on-line trading has taken so many experts by surprise, however, is that, given the many scare stories about security hazards on-line, it seems incredible that people would trust their real money to it. After all, they sure didn't buy electronic cash. —*Wendy M. Grossman*

WENDY M. GROSSMAN, a writer based in London, likes firms that pay regular dividends but warns that past results do not guarantee future performance.

Negative Energy, Wormholes and Warp Drive

The construction of wormholes and warp drive would require a very unusual form of energy. Unfortunately, the same laws of physics that allow the existence of this "negative energy" also appear to limit its behavior

by Lawrence H. Ford and Thomas A. Roman

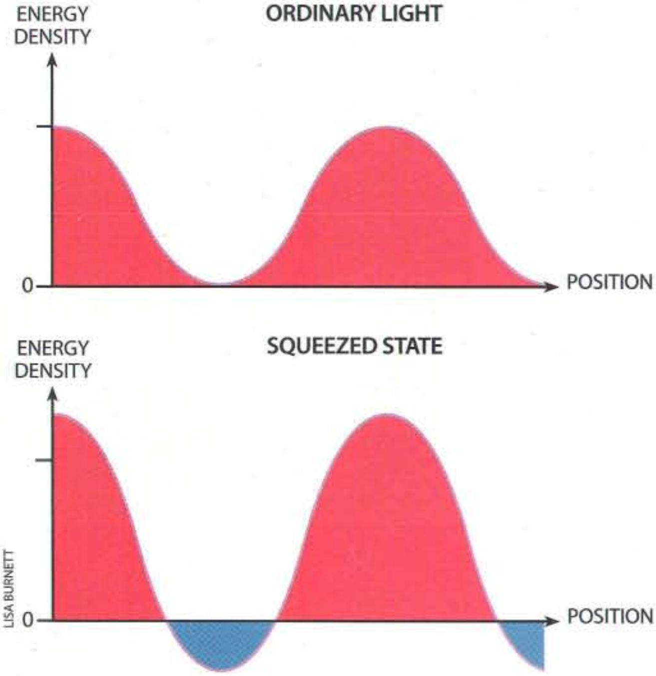


SLIM FILMS; DAN WAGNER (*Times Square*); JULIA WATERLOW Corbis (*Sahara*)

Can a region of space contain less than nothing? Common sense would say no; the most one could do is remove all matter and radiation and be left with vacuum. But quantum physics has a proven ability to confound intuition, and this case is no exception. A region of space, it turns out, can contain less than nothing. Its energy per unit volume—the energy density—can be less than zero.

Needless to say, the implications are bizarre. According to Einstein's theory of gravity, general relativity, the presence of matter and energy warps the geometric fabric of space and time. What we perceive as gravity is the space-time distortion produced by normal, positive energy or mass. But when negative energy or mass—so-called exotic matter—bends space-time, all sorts of amazing phenomena might become possible: traversable wormholes, which could act as tunnels to otherwise dis-

IF A WORMHOLE COULD EXIST, it would appear as a spherical opening to an otherwise distant part of the cosmos. In this doctored photograph of Times Square, the wormhole allows New Yorkers to walk to the Sahara with a single step, rather than spending hours on the plane to Tamanrasset. Although such a wormhole does not break any known laws of physics, it would require the production of unrealistic amounts of negative energy.



WAVES OF LIGHT ordinarily have a positive or zero energy density at different points in space (*top*). But in a so-called squeezed state, the energy density at a particular instant in time can become negative at some locations (*bottom*). To compensate, the peak positive density must increase.

tant parts of the universe; warp drive, which would allow for faster-than-light travel; and time machines, which might permit journeys into the past. Negative energy could even be used to make perpetual-motion machines or to destroy black holes. A *Star Trek* episode could not ask for more.

For physicists, these ramifications set off alarm bells. The potential paradoxes of backward time travel—such as killing your grandfather before your father is conceived—have long been explored in science fiction, and the other consequences of exotic matter are also problematic. They raise a question of fundamental importance: Do the laws of physics that permit negative energy place any limits on its behavior? We and others have discovered that nature imposes stringent constraints on the magnitude and duration of negative energy, which (unfortunately, some would say) appear to render the construction of wormholes and warp drives very unlikely.

Double Negative

Before proceeding further, we should draw the reader's attention to what negative energy is not. It should not be confused with antimatter, which has positive energy. When an electron and its antiparticle, a positron, collide, they annihilate. The end products are gamma rays, which carry positive energy. If antiparticles were composed of negative energy, such an interaction would result in a final energy of zero. One should also not confuse negative energy with the energy associated with the cosmological constant, postulated in inflationary models of the universe [see "Cosmological Antigravity," by Lawrence M. Krauss; SCIENTIFIC AMERICAN, January 1999]. Such a constant represents negative pressure but positive energy. (Some authors call this exotic matter; we reserve the term for negative energy densities.)

The concept of negative energy is not pure fantasy; some of its effects have even been produced in the laboratory. They arise from Heisenberg's uncertainty principle, which requires that the energy density of any electric, magnetic or other field fluctuate randomly. Even when the energy density is zero on average, as in a vacuum, it fluctuates. Thus, the quantum vacuum can never remain empty in the classical sense of the term; it is a roiling sea of "virtual" particles spontaneously popping in and out of existence [see "Exploiting Zero-Point Energy," by Philip Yam; SCIENTIFIC AMERICAN, December 1997]. In quantum theory, the usual notion of zero energy corresponds to the vacuum with all these fluctuations. So if one can somehow contrive to dampen the undulations, the vacuum will have less energy than it normally does—that is, less than zero energy.

As an example, researchers in quantum optics have created special states of fields in which destructive quantum interference suppresses the vacuum fluctuations. These so-called squeezed vacuum states involve negative energy. More precisely, they are associated with regions of alternating positive and negative energy. The total energy averaged over all space remains positive; squeezing the vacuum creates negative energy in one place at the price of extra positive energy elsewhere. A typical experiment involves laser beams passing through nonlinear optical materials [see "Squeezed Light," by Richart E. Slusher and Bernard Yurke; SCIENTIFIC AMERICAN, May 1988]. The intense laser light induces the material to create pairs of light quanta, photons. These photons alternately enhance and suppress the vacuum fluctuations, leading to regions of positive and negative energy, respectively.

Another method for producing negative energy introduces geometric boundaries into a space. In 1948 Dutch physicist Hendrik B. G. Casimir showed that two uncharged parallel metal plates alter the vacuum fluctuations in such a way as to attract each other. The energy density between the plates was later calculated to be negative. In effect, the plates reduce the fluctuations in the gap between them; this creates negative energy and pressure, which pulls the plates together. The narrower the gap, the more negative the energy and pressure, and the stronger is the attractive force. The Casimir effect has recently been measured by Steve K. Lamoreaux of Los Alamos National Laboratory and by Umar Mohideen of the University of California at Riverside and his colleague Anushree Roy. Similarly, in the 1970s Paul C. W. Davies and Stephen A. Fulling, then at King's College at the University of London, predicted that a moving boundary, such as a moving mirror, could produce a flux of negative energy.

For both the Casimir effect and squeezed states, researchers have measured only the indirect effects of negative energy. Direct detection is more difficult but might be possible using atomic spins, as Peter G. Grove, then at the British Home Office, Adrian C. Ottewill, then at the University of Oxford, and one of us (Ford) suggested in 1992.

Gravity and Levity

The concept of negative energy arises in several areas of modern physics. It has an intimate link with black holes, those mysterious objects whose gravitational field is so strong that nothing can escape from within their boundary, the event horizon. In 1974 Stephen W. Hawking of the University of Cambridge made his famous prediction that black holes evaporate by emitting radiation [see "The Quantum Mechanics of Black Holes," by Stephen W. Hawking; SCIENTIFIC AMERICAN, January 1977]. A black hole radiates energy at a rate inversely proportional to the square of its mass.

Although the evaporation rate is large only for subatomic-size black holes, it provides a crucial link between the laws of black holes and the laws of thermodynamics. The Hawking radiation allows black holes to come into thermal equilibrium with their environment.

At first glance, evaporation leads to a contradiction. The horizon is a one-way street; energy can only flow inward. So how can a black hole radiate energy outward? Because energy must be conserved, the production of positive energy—which distant observers see as the Hawking radiation—is accompanied by a flow of negative energy into the hole. Here the negative energy is produced by the extreme space-time curvature near the hole, which disturbs the vacuum fluctuations. In this way, negative energy is required for the consistency of the unification of black hole physics with thermodynamics.

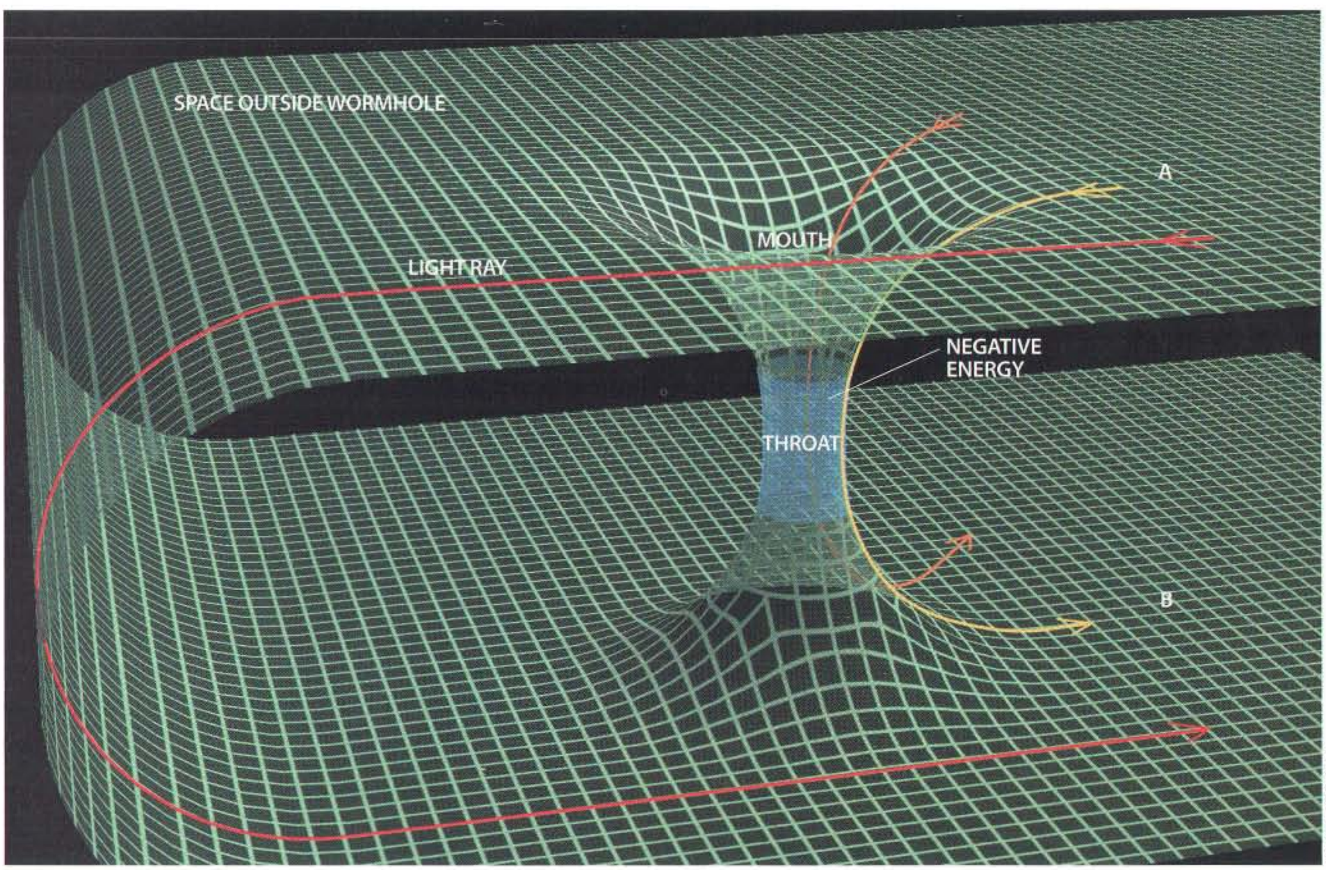
The black hole is not the only curved region of space-time where negative energy seems to play a role. Another is the wormhole—a hypothesized type of tunnel that connects one region of space and time to another. Physicists used to think that wormholes exist only on the very finest length scales, bubbling in and out of existence like virtual particles [see "Quantum Gravity," by Bryce S. DeWitt; SCIENTIFIC AMERICAN, December 1983]. In the early 1960s physicists Robert Fuller and John A. Wheeler showed that larger wormholes would collapse under their own gravity so rapidly that even a beam of light would not have enough time to travel through them.

But in the late 1980s various researchers—notably Michael S. Morris and Kip S. Thorne of the California Institute of Technology and Matt Visser of Washington University—found otherwise. Certain wormholes could in fact be made large enough for a person or spaceship. Someone might enter the mouth of a wormhole stationed on Earth, walk a short distance inside the wormhole and exit the other mouth in, say, the Andromeda galaxy. The catch is that traversable wormholes require negative energy. Because negative energy is gravitationally repulsive, it would prevent the wormhole from collapsing.

For a wormhole to be traversable, it ought to (at bare minimum) allow signals, in the form of light rays, to pass through it. Light rays entering one mouth of a wormhole are converging, but to emerge from the other mouth, they must defocus—in other words, they must go from converging to diverging somewhere in between [*see illustration below*]. This defocusing requires negative energy. Whereas the curvature of space produced by the attractive gravitational field of ordinary matter acts like a converging lens, negative energy acts like a diverging lens.

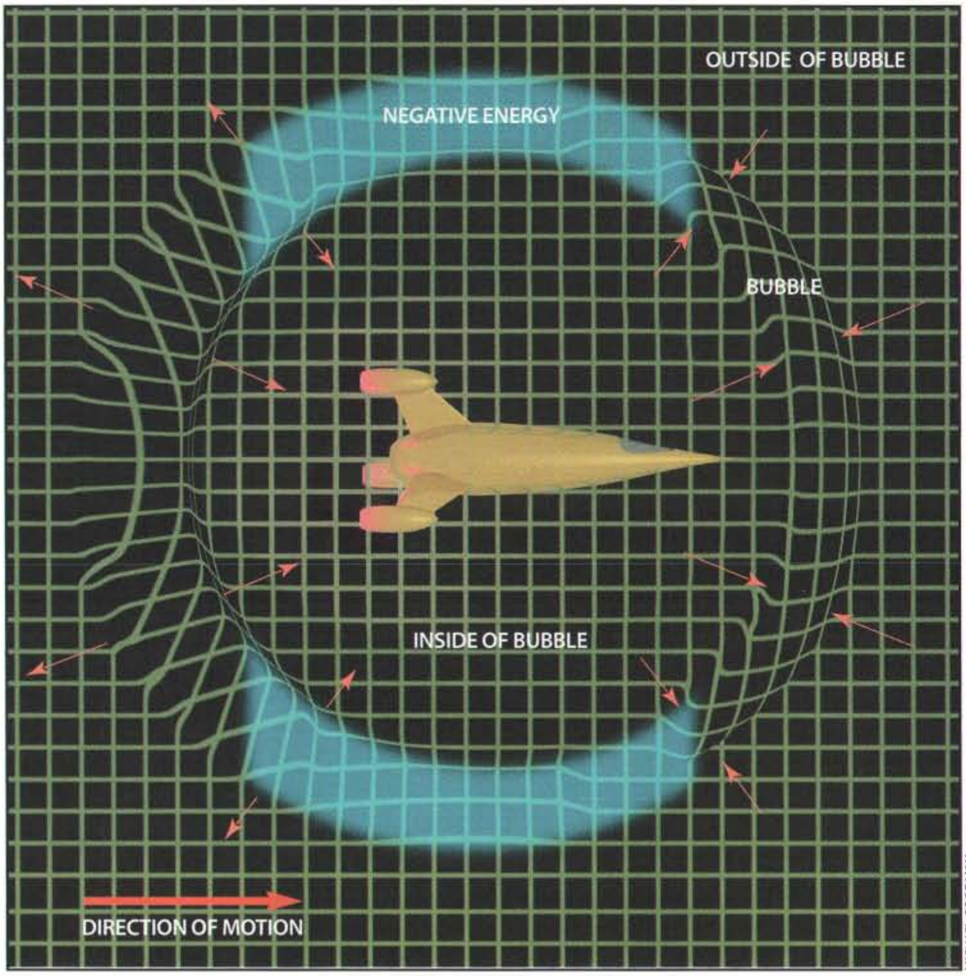
No Dilithium Needed

Such space-time contortions would enable another staple of science fiction as well: faster-than-light travel. In 1994 Miguel Alcubierre Moya, then at the University of Wales at Cardiff, discovered a solution to Einstein's equations that has



WORMHOLE acts as a tunnel between two different locations in space. Light rays from A to B can enter one mouth of the wormhole, pass through the throat and exit at the other mouth—a journey that would take much longer if they had to go the long way around. At the throat must be negative energy (*blue*), whose gravitational field allows converging light rays to begin diverging. (This diagram is a two-dimensional representation of three-dimensional space. The mouths and throat of the wormhole are actually spheres.) Although not shown here, a wormhole could also connect two different points in time.

SPACE-TIME BUBBLE is the closest that modern physics comes to the "warp drive" of science fiction. It can convey a starship at arbitrarily high speeds. Space-time contracts at the front of the bubble, reducing the distance to the destination, and expands at its rear, increasing the distance from the origin (*arrows*). The ship itself stands still relative to the space immediately around it; crew members do not experience any acceleration. Negative energy (*blue*) is required on the sides of the bubble.



many of the desired features of warp drive. It describes a space-time bubble that transports a starship at arbitrarily high speeds relative to observers outside the bubble. Calculations show that negative energy is required.

Warp drive might appear to violate Einstein's special theory of relativity. But special relativity says that you cannot outrun a light signal in a fair race in which you and the signal follow the same route. When space-time is warped, it might be possible to beat a light signal by taking a different route, a shortcut. The contraction of space-time in front of the bubble and the expansion behind it create such a shortcut [*see illustration above*].

One problem with Alcubierre's original model, pointed out by Sergei V. Krasnikov of the Central Astronomical Observatory at Pulkovo near St. Petersburg, is that the interior of the warp bubble is causally disconnected from its forward edge. A starship captain on the inside cannot steer the bubble or turn it on or off; some external agency must set it up ahead of time. To get around this problem, Krasnikov proposed a "superluminal subway," a tube of modified space-time (not the same as a wormhole) connecting Earth and a distant star. Within the tube, superluminal travel in one direction is possible. During the outbound journey at sublight speed, a spaceship crew would create such a tube. On the return journey, they could travel through it at warp speed. Like warp bubbles, the subway involves negative energy. It has since been shown by Ken D. Olum of Tufts University and by Visser, together with Bruce Bassett of Oxford and Stefano Liberati of the International School for Advanced Studies in Trieste, that any scheme for faster-than-light travel requires the use of negative energy.

If one can construct wormholes or warp drives, time travel might become possible. The passage of time is relative; it depends on the observer's velocity. A person who leaves Earth in a spaceship, travels at near lightspeed and returns will have aged less than someone who remains on Earth. If the traveler manages to outrun a light ray, perhaps by taking a shortcut through a wormhole or a warp bubble, he may return before he left. Morris, Thorne and Ulvi Yurtsever, then at Caltech, proposed a wormhole time machine in 1988, and their paper has stimulated much research on time travel over the past decade. In 1992 Hawking proved that any construction of a time machine in a finite region of space-time inherently requires negative energy.

Negative energy is so strange that one might think it must violate some law of physics. Before and after the creation of equal amounts of negative and positive energy in previously empty space, the total energy is zero, so the law of conservation of energy is obeyed. But there are many phenomena that conserve energy yet never occur in the real world. A broken glass does not reassemble itself, and heat does not spontaneously flow from a colder to a hotter body. Such effects are forbidden by the second law of thermodynamics. This general principle states that the degree of disorder of a system—its entropy—cannot decrease on its own without an input of energy. Thus, a refrigerator, which pumps heat from its cold interior to the warmer outside room, requires an external power source. Similarly, the second law also forbids the complete conversion of heat into work.

MICHAEL GOODMAN; SOURCE: CHAD CLARK, WILLIAM A. HISCOCK AND SHANE L. LARSON *Montana State University*

VIEW FROM THE BRIDGE of a faster-than-light starship as it heads in the direction of the Little Dipper (*above*) looks nothing like the star streaks typically depicted in science fiction. As the velocity increases (*right*), stars ahead of the ship (*left column*) appear ever closer to the direction of motion and turn bluer in color. Behind the ship (*right column*), stars shift closer to a position directly astern, redden and eventually disappear from view altogether. The light from stars directly overhead or underneath remains unaffected.

Negative energy potentially conflicts with the second law. Imagine an exotic laser, which creates a steady outgoing beam of negative energy. Conservation of energy requires that a byproduct be a steady stream of positive energy. One could direct the negative energy beam off to some distant corner of the universe, while employing the positive energy to perform useful work. This seemingly inexhaustible energy supply could be used to make a perpetual-motion machine and thereby violate the second law. If the beam were directed at a glass of water, it could cool the water while using the extracted positive energy to power a small motor—providing a refrigerator with no need for external power. These problems arise not from the existence of negative energy per se but from the unrestricted separation of negative and positive energy.

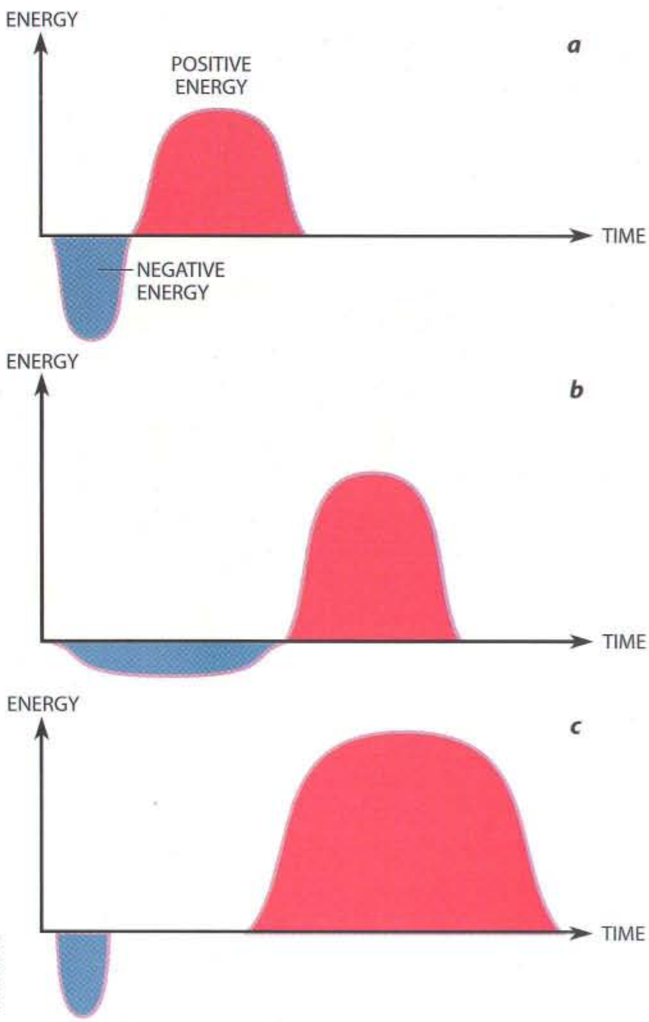
Unfettered negative energy would also have profound consequences for black holes. When a black hole forms by the collapse of a dying star, general relativity predicts the formation of a singularity, a region where the gravitational field becomes infinitely strong. At this point, general relativity—and indeed all known laws of physics—are unable to say what happens next. This inability is a profound failure of the current mathematical description of nature. So long as the singularity is hidden within an event horizon, however, the damage is limited. The description of nature everywhere outside of the horizon is unaffected. For this reason, Roger Penrose of Oxford proposed the cosmic censorship hypothesis: there can be no naked singularities, which are unshielded by event horizons.

For special types of charged or rotating black holes—known as extreme black holes—even a small increase in charge or spin, or a decrease in mass, could in principle destroy the horizon and convert the hole into a naked singularity. Attempts to charge up or spin up these black holes using ordinary matter seem to fail for a variety of reasons. One might instead envision producing a decrease in mass by shining a beam of negative energy down the hole, without altering its charge or spin, thus subverting cosmic censorship. One might create such a beam, for example, using a moving mirror. In principle, it would require only a tiny amount of negative energy to produce a dramatic change in the state of an extreme black hole. Therefore, this might be the scenario in which negative energy is the most likely to produce macroscopic effects.

Not Separate and Not Equal

Fortunately (or not, depending on your point of view), although quantum theory allows the existence of negative energy, it also appears to place strong restrictions—known as quantum inequalities—on its magnitude and duration. These inequalities were first suggested by Ford in 1978. Over the past decade they have been proved and refined by us and others, including Éanna E. Flanagan of Cornell University, Michael J. Pfenning, then at Tufts, Christopher J. Fewster and Simon P. Eveson of the University of York, and Edward Teo of the National University of Singapore.

The inequalities bear some resemblance to the uncertainty



LISA BURNETT

PULSES OF NEGATIVE ENERGY are permitted by quantum theory but only under three conditions. First, the longer the pulse lasts, the weaker it must be (*a, b*). Second, a pulse of positive energy must follow. The magnitude of the positive pulse must exceed that of the initial negative one. Third, the longer the time interval between the two pulses, the larger the positive one must be—an effect known as quantum interest (*c*).

principle. They say that a beam of negative energy cannot be arbitrarily intense for an arbitrarily long time. The permissible magnitude of the negative energy is inversely related to its temporal or spatial extent. An intense pulse of negative energy can last for a short time; a weak pulse can last longer. Furthermore, an initial negative energy pulse must be followed by a larger pulse of positive energy [*see illustration above*]. The larger the magnitude of the negative energy, the nearer must be its positive energy counterpart. These restrictions are independent of the details of how the negative energy is produced. One can think of negative energy as an energy loan. Just as a debt is negative money that has to be repaid, negative energy is an energy deficit. As we will discuss below, the analogy goes even further.

In the Casimir effect, the negative energy density between the plates can persist indefinitely, but large negative energy densities require a very small plate separation. The magnitude of the negative energy density is inversely proportional to the fourth power of the plate separation. Just as a pulse with a very negative energy density is limited in time, very negative Casimir energy density must be confined between closely spaced plates. According to the quantum inequalities, the energy density in the gap can be made more negative than the Casimir value, but only temporarily. In effect, the more one tries to depress the energy density below the Casimir value, the shorter the time over which this situation can be maintained.

When applied to wormholes and warp drives, the quantum inequalities typically imply that such structures must either be limited to submicroscopic sizes, or if they are macroscopic the negative energy must be confined to incredibly thin bands. In 1996 we showed that a submicroscopic wormhole would have a throat radius of no more than about 10^{-32} meter. This is only slightly larger than the Planck length, 10^{-35} meter, the smallest distance that has definite meaning. We found that it is possible to have models of wormholes of macroscopic size but only at the price of confining the negative energy to an extremely thin band around the throat. For example, in one model a throat radius of 1 meter requires the negative energy to be a band no thicker than 10^{-21} meter, a millionth the size of a proton. Visser has estimated that the negative energy required for this size of wormhole has a magnitude equivalent to the total energy generated by 10 billion stars in one year. The situation does not improve much for larger wormholes. For the same model, the maximum allowed thickness of the negative energy band is proportional to the cube root of the throat radius. Even if the throat radius is increased to a size of one light-year, the negative energy must still be confined to a region smaller than a proton radius, and the total amount required increases linearly with the throat size.

It seems that wormhole engineers face daunting problems. They must find a mechanism for confining large amounts of negative energy to extremely thin volumes. So-called cosmic strings, hypothesized in some cosmological theories, involve very large energy densities in long, narrow lines. But all known physically reasonable cosmic-string models have positive energy densities.

Warp drives are even more tightly constrained, as shown by Pfenning and Allen Everett of Tufts, working with us. In Alcubierre's model, a warp bubble traveling at 10 times lightspeed (warp factor 2, in the parlance of *Star Trek: The Next Generation*) must have a wall thickness of no more than 10^{-32} meter. A bubble large enough to enclose a starship 200 meters across would require a total amount of negative energy equal to 10 billion times the mass of the observable universe. Similar constraints apply to Krasnikov's superluminal subway. A modification of Alcubierre's model was recently constructed by Chris Van Den Broeck of the Catholic University of Louvain in Belgium. It requires much less negative energy but places the starship in a curved space-time bottle whose neck is about 10^{-32} meter across, a difficult feat. These results would seem to make it rather unlikely that one could construct wormholes and warp drives using negative energy generated by quantum effects.

Cosmic Flashing and Quantum Interest

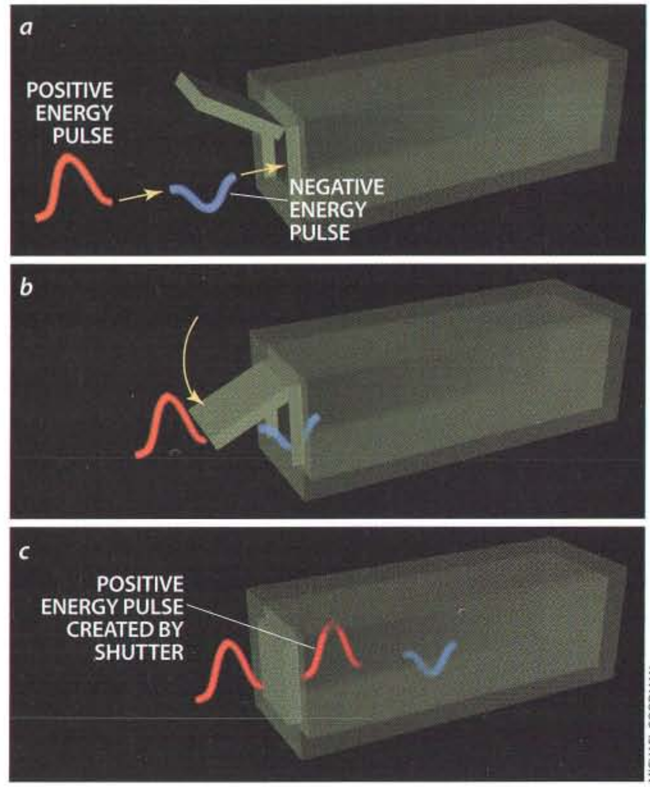
The quantum inequalities prevent violations of the second law. If one tries to use a pulse of negative energy to cool a hot object, it will be quickly followed by a larger pulse of positive energy, which reheats the object. A weak pulse of negative energy could remain separated from its positive counterpart for a longer time, but its effects would be indistinguishable from normal thermal fluctuations. Attempts to capture or split off negative energy from positive energy also appear to fail. One might intercept an energy beam, say, by

using a box with a shutter. By closing the shutter, one might hope to trap a pulse of negative energy before the offsetting positive energy arrives. But the very act of closing the shutter creates an energy flux that cancels out the negative energy it was designed to trap [*see illustration at right*].

We have shown that there are similar restrictions on violations of cosmic censorship. A pulse of negative energy injected into a charged black hole might momentarily destroy the horizon, exposing the singularity within. But the pulse must be followed by a pulse of positive energy, which would convert the naked singularity back into a black hole—a scenario we have dubbed cosmic flashing. The best chance to observe cosmic flashing would be to maximize the time separation between the negative and positive energy, allowing the naked singularity to last as long as possible. But then the magnitude of the negative energy pulse would have to be very small, according to the quantum inequalities. The change in the mass of the black hole caused by the negative energy pulse will get washed out by the normal quantum fluctuations in the hole's mass, which are a natural consequence of the uncertainty principle. The view of the naked singularity would thus be blurred, so a distant observer could not unambiguously verify that cosmic censorship had been violated.

Recently we, and also Frans Pretorius, then at the University of Victoria, and Fewster and Teo, have shown that the quantum inequalities lead to even stronger bounds on negative energy. The positive pulse that necessarily follows an initial negative pulse must do more than compensate for the negative pulse; it must overcompensate. The amount of overcompensation increases with the time interval between the pulses. Therefore, the negative and positive pulses can never be made to exactly cancel each other. The positive energy must always dominate—an effect known as quantum interest. If negative energy is thought of as an energy loan, the loan must be repaid with interest. The longer the loan period or the larger the loan amount, the greater is the interest. Furthermore, the larger the loan, the smaller is the maximum allowed loan period. Nature is a shrewd banker and always calls in its debts.

The concept of negative energy touches on many areas of physics: gravitation, quantum theory, thermodynamics. The interweaving of so many different parts of physics illustrates the tight logical structure of the laws of nature. On the one hand, negative energy seems to be required to reconcile black holes with thermodynamics. On the other, quantum physics prevents unrestricted production of negative energy, which would violate the second law of thermodynamics. Whether these restrictions are also features of some deeper underlying theory, such as quantum gravity, remains to be seen. Nature no doubt has more surprises in store.



ATTEMPT TO CIRCUMVENT the quantum laws that govern negative energy inevitably ends in disappointment. The experimenter intends to detach a negative energy pulse from its compensating positive energy pulse. As the pulses approach a box (*a*), the experimenter tries to isolate the negative one by closing the lid after it has entered (*b*). Yet the very act of closing the lid creates a second positive energy pulse inside the box (*c*).

The Authors

LAWRENCE H. FORD and THOMAS A. ROMAN have collaborated on negative energy issues for over a decade. Ford received his Ph.D. from Princeton University in 1974, working under John Wheeler, one of the founders of black hole physics. He is now a professor of physics at Tufts University and works on problems in both general relativity and quantum theory, with a special interest in quantum fluctuations. His other pursuits include hiking in the New England woods and gathering wild mushrooms. Roman received his Ph.D. in 1981 from Syracuse University under Peter Bergmann, who collaborated with Albert Einstein on unified field theory. Roman has been a frequent visitor at the Tufts Institute of Cosmology during the past 10 years and is currently a professor of physics at Central Connecticut State University. His interests include the implications of negative energy for a quantum theory of gravity. He tends to avoid wild mushrooms.

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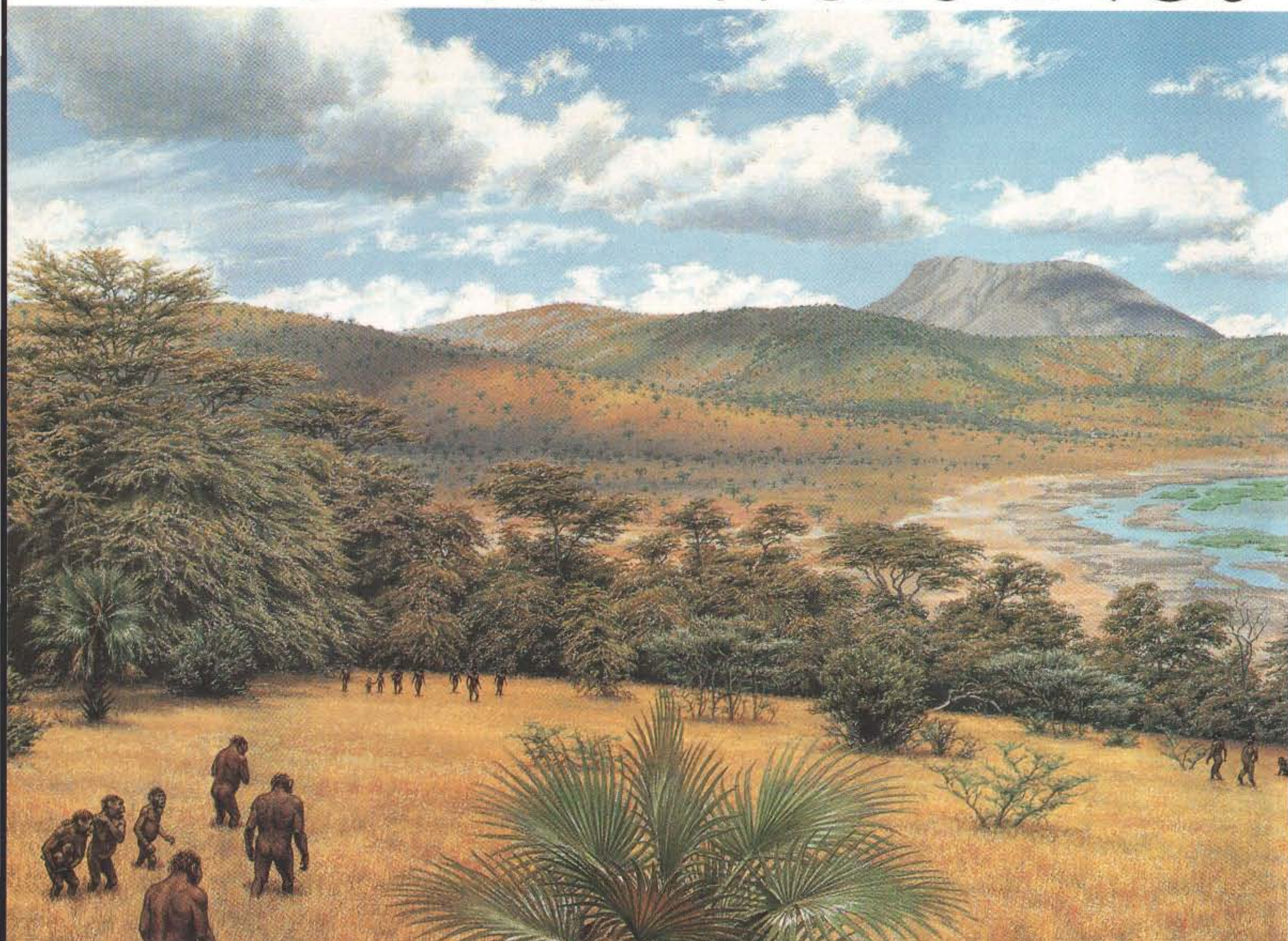
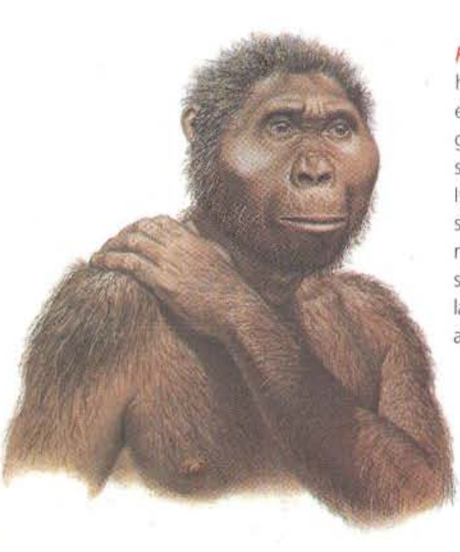
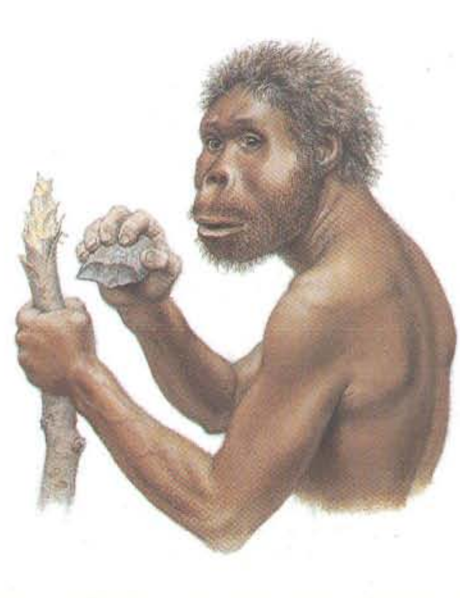
Today we take for granted that Homo sapiens *is the only hominid on Earth. Yet for at least four million years man*

Once We Were Not





PARANTHROPUS BOISEI had massive jaws, equipped with huge grinding teeth for a presumed vegetarian diet. Its skull is accordingly strongly built, but it is not known if in body size it was significantly larger than the "gracile" australopiths.



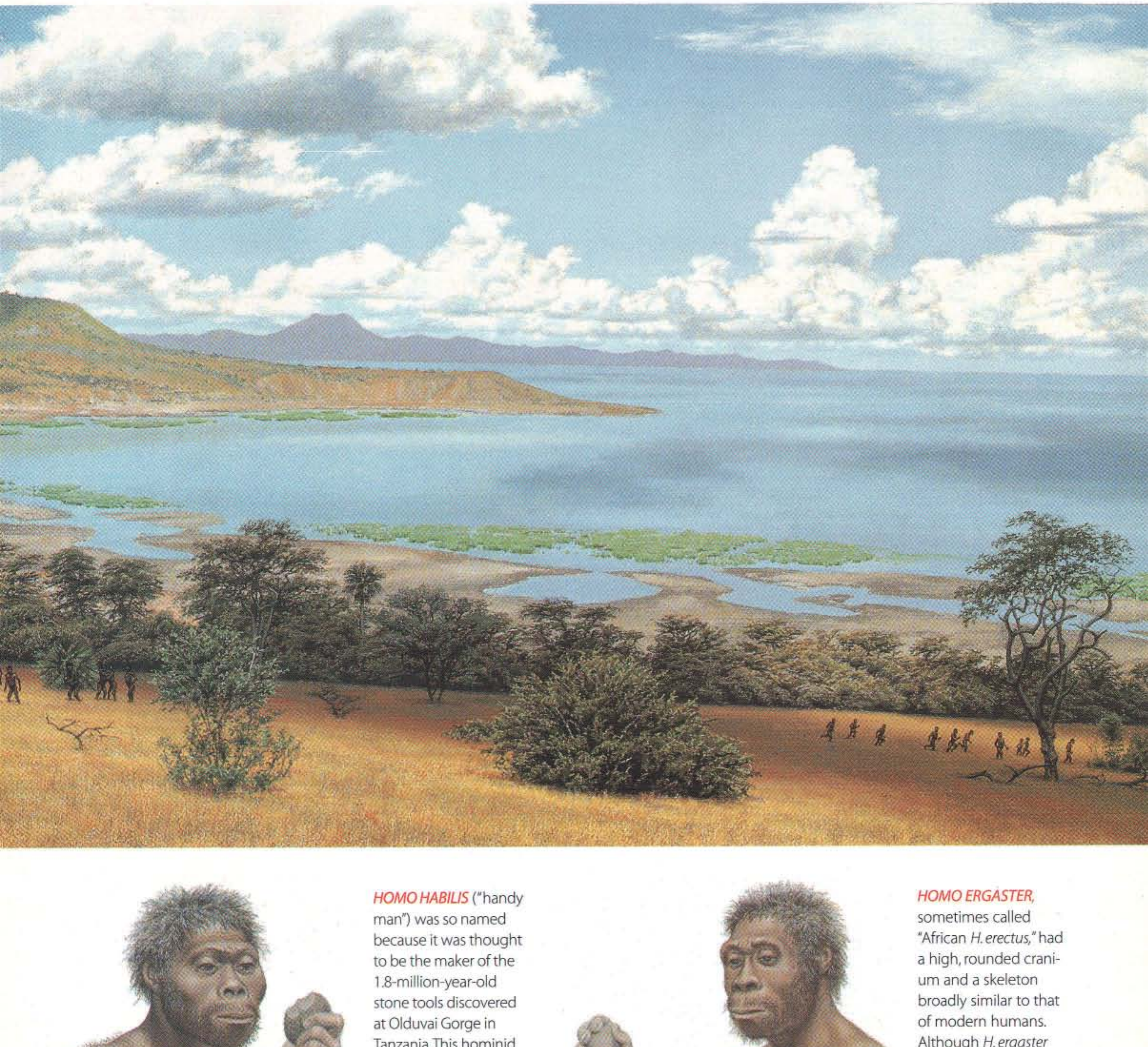
HOMO RUDOLFENSIS was a relatively large-brained hominid, typified by the famous KNM-ER 1470 cranium. Its skull was distinct from the apparently smaller-brained *H. habilis*, but its body proportions are effectively unknown.

hominid species shared the planet. What makes us different?

Alone

by Ian Tattersall
Paintings by Jay H. Matternes

SHARING A SINGLE LANDSCAPE, four kinds of hominids lived about 1.8 million years ago in what is now part of northern Kenya. Although paleoanthropologists have no idea how—or if—these different species interacted, they do know that *Paranthropus boisei, Homo rudolfensis, H. habilis* and *H. ergaster* foraged in the same area around Lake Turkana.



HOMO HABILIS ("handy man") was so named because it was thought to be the maker of the 1.8-million-year-old stone tools discovered at Olduvai Gorge in Tanzania. This hominid fashioned sharp flakes by banging one rock cobble against another.

HOMO ERGASTER, sometimes called "African *H. erectus,*" had a high, rounded cranium and a skeleton broadly similar to that of modern humans. Although *H. ergaster* clearly ate meat, its chewing teeth are relatively small. The best specimen of this hominid is that of an adolescent from about 1.6 million years ago known as "Turkana boy."

Homo sapiens has had the earth to itself for the past 25,000 years or so, free and clear of competition from other members of the hominid family. This period has evidently been long enough for us to have developed a profound feeling that being alone in the world is an entirely natural and appropriate state of affairs.

So natural and appropriate, indeed, that during the 1950s and 1960s a school of thought emerged that, in essence, claimed that only one species of hominid could have existed at a time because there was simply no ecological space on the planet for more than one culture-bearing species. The "single-species hypothesis" was never very convincing—even in terms of the rather sparse hominid fossil record of 35 years ago. But the implicit scenario of the slow, single-minded transformation of the bent and benighted ancestral hominid into the graceful and gifted modern *H. sapiens* proved powerfully seductive—as fables of frogs becoming princes always are.

So seductive that it was only in the late 1970s, following the discovery of incontrovertible fossil evidence that hominid species coexisted some 1.8 million years ago in what is now northern Kenya, that the single-species hypothesis was abandoned. Yet even then, paleoanthropologists continued to cleave to a rather minimalist interpretation of the fossil record. Their tendency was to downplay the number of species and to group together distinctively different fossils under single, uninformative epithets such as "archaic *Homo sapiens*." As a result, they tended to lose sight of the fact that many kinds of hominids had regularly contrived to coexist.

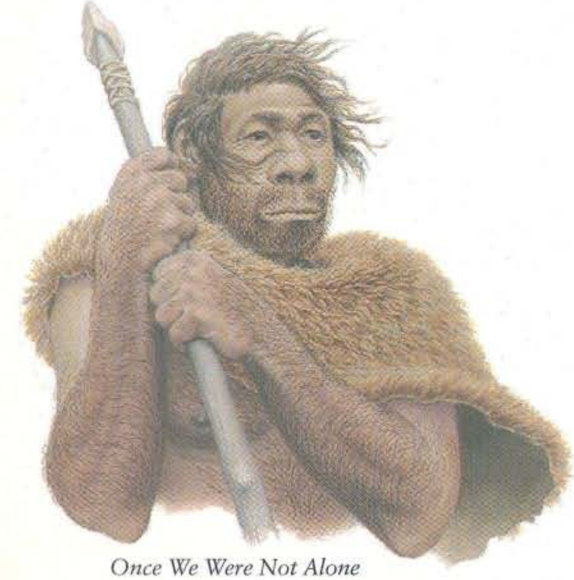
Although the minimalist tendency persists, recent discoveries and fossil reappraisals make clear that the biological history of hominids resembles that of most other successful animal families. It is marked by diversity rather than by linear progression. Despite this rich history—during which hominid species developed and lived together and competed and rose and fell—*H. sapiens* ultimately emerged as the sole hominid. The reasons for this are generally unknowable, but different interactions between the last coexisting hominids—*H. sapiens* and *H. neanderthalensis*—in two distinct geographical regions offer some intriguing insights.

A Suite of Species

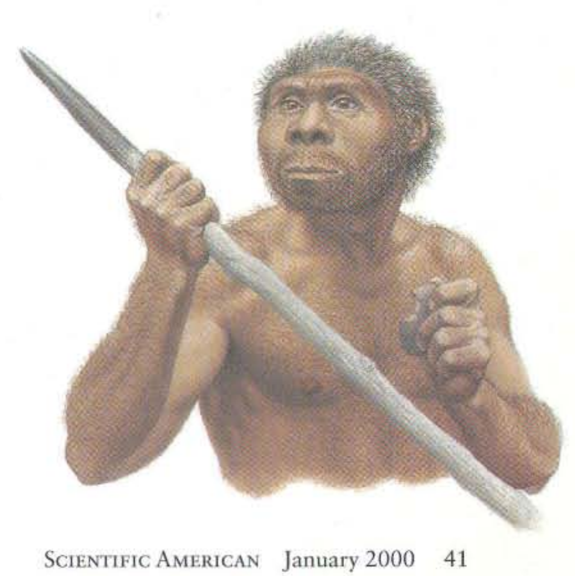
From the beginning, almost from the very moment the earliest hominid biped—the first "australopith"—made its initial hesitant steps away from the forest depths, we have evidence for hominid diversity. The oldest-known potential hominid is *Ardipithecus ramidus*, represented by some fragmentary fossils from the 4.4-million-year-old site of Aramis in Ethiopia [*see diagram on page 42*]. Only slightly younger is the better-known *Australopithecus anamensis*, from sites in northern Kenya that are about 4.2 million years old.

Ardipithecus, though claimed on indirect evidence to have been an upright walker, is quite apelike in many respects. In contrast, *A. anamensis* looks reassuringly similar to the 3.8- to 3.0-million-year-old *Australopithecus afarensis*, a small-brained, big-faced bipedal species to which the famous "Lucy" belonged. Many remnants of *A. afarensis* have been found in various eastern African sites, but some researchers have suggested that the mass of fossils described as *A. afarensis* may contain more than one species, and it is only a matter of time until the subject is raised again. In any event, *A. afarensis* was not alone in Africa. A distinctive jaw, from an australopith named *A. bahrelghazali*, was recently found in Chad. It is probably between 3.5 and 3.0 million years old and is thus roughly coeval with Lucy.

In southern Africa, scientists have just reported evidence of another primitive bipedal hominid species. As yet unnamed and undescribed, this distinctive form is 3.3 million years old. At about 3 million years ago, the same region begins to yield fossils of *A. africanus*, the first australopith to be discovered (in 1924). This species may have persisted until not much more than 2 million years ago. A recently named 2.5-million-year-old species from Ethiopia, *Australopithecus garhi*, is claimed to fall in an intermediate position between *A. afarensis*, on the one hand, and a larger group that includes more recent australopiths and *Homo*, on the other. Almost exactly the same age is the first representative of the "robust" group of australopiths, *Paranthropus aethiopicus*.



TUC D'AUDOUBERT CAVE in France was entered sometime between perhaps 11,000 and 13,000 years ago by *H. sapiens*, also called Cro Magnons, who sculpted small clay bison in a recess almost a mile underground. Hominids of modern body form most likely emerged in Africa at around 150,000 years ago and coexisted with other hominids for a time before emerging as the only species of our family. Until about 30,000 years ago, they overlapped with *H. neanderthalensis* (*left*) in Europe and in the Levant, and they may have been contemporaneous with the *H. erectus* (*right*) then living in Java.



This early form is best known from the 2.5-million-year-old "Black Skull" of northern Kenya, and in the period between about 2 and 1.4 million years ago the robusts were represented all over eastern Africa by the familiar *P. boisei*. In South Africa, during the period around 1.6 million years ago, the robusts included the distinctive *P. robustus* and possibly also a closely related second species, *P. crassidens*.

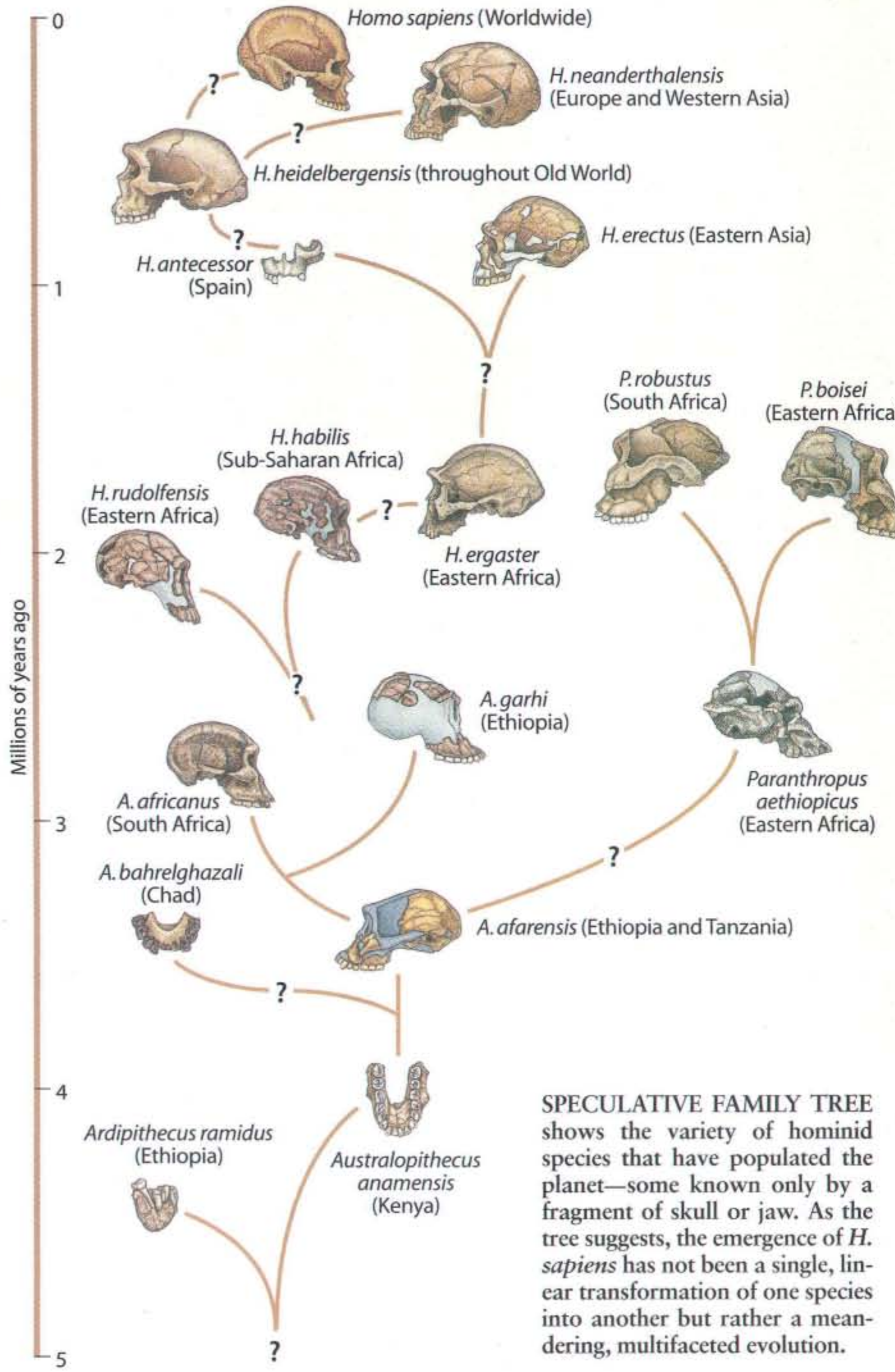
I apologize for inflicting this long list of names on you, but in fact it actually underestimates the number of australopith species that existed. What is more, we don't know how long each of these creatures lasted. Nevertheless, even if average species longevity was only a few hundred thousand years, it is clear that from the very beginning the continent of Africa was at least periodically—and most likely continually—host to multiple kinds of hominids.

The appearance of the genus *Homo* did nothing to perturb this pattern. The 2.5- to 1.8-million-year-old fossils from eastern and southern Africa that announce the earliest appearance of *Homo* are an oddly assorted lot and probably a lot more diverse than their conventional assignment to the two species *H. habilis* and *H. rudolfensis* indicates. Still, at Kenya's East Turkana, in the period between 1.9 and 1.8 million years ago, these two species were joined not only by the ubiquitous *P. boisei* but by *H. ergaster*, the first hominid of essentially modern body form. Here, then, is evidence for four hominid species sharing not just the same continent but the same landscape [*see illustration on pages 38 and 39*].

The first exodus of hominids from Africa, presumably in the form of *H. ergaster* or a close relative, opened a vast prospect for further diversification. One could wish for a better record of this movement, and particularly of its dating, but there are indications that hominids of some kind had reached China and Java by about 1.8 million years ago. A lower jaw that may be about the same age from Dmanisi in ex-Soviet Georgia is distinctively different from anything else yet found [see "Out of Africa Again ... and Again?," by Ian Tattersall; SCIENTIFIC AMERICAN, April 1997]. By the million-year mark *H. erectus* was established in both Java and China, and it is possible that a more robust hominid species was present in Java as well. At the other end of the Eurasian continent, the oldest-known European hominid fragments—from about 800,000 years ago—are highly distinctive and have been dubbed *H. antecessor* by their Spanish discoverers.

About 600,000 years ago, in Africa, we begin to pick up evidence for *H. heidelbergensis*, a species also seen at sites in Europe—and possibly China—between 500,000 to 200,000 years ago. As we learn more about *H. heidelbergensis*, we are likely to find that more than one species is actually represented in this group of fossils. In Europe, *H. heidelbergensis* or a relative gave rise to an endemic group of hominids whose best-known representative was *H. neanderthalensis*, a European and western Asian species that flourished between about 200,000 and 30,000 years ago. The sparse record from Africa suggests that at this time independent developments were taking place there, too—including the emergence of *H. sapiens*. And in Java, possible *H. erectus* fossils from Ngandong have just been dated to around 40,000 years ago, implying that this area had its own indigenous hominid evolutionary history for perhaps millions of years as well.

The picture of hominid evolution just sketched is a far cry from the "*Australopithecus africanus* begat *Homo erectus*



SPECULATIVE FAMILY TREE shows the variety of hominid species that have populated the planet—some known only by a fragment of skull or jaw. As the tree suggests, the emergence of *H. sapiens* has not been a single, linear transformation of one species into another but rather a meandering, multifaceted evolution.

PATRICIA J. WYNNE (*drawings*)

begat *Homo sapiens*" scenario that prevailed 40 years ago—and it is, of course, based to a great extent on fossils that have been discovered since that time. Yet the dead hand of linear thinking still lies heavily on paleoanthropology, and even today many of my colleagues would argue that this scenario overestimates diversity. There are various ways of simplifying the picture, most of them involving the cop-out of stuffing all variants of *Homo* of the last half a million or even two million years into the species *H. sapiens*.

My own view, in contrast, is that the 20 or so hominid species invoked (if not named) above represent a minimum estimate. Not only is the human fossil record as we know it full of largely unacknowledged morphological indications of diversity, but it would be rash to claim that every hominid species that ever existed is represented in one fossil collection or another. And even if only the latter is true, it is still clear that the story of human evolution has not been one of a lone hero's linear struggle.

Instead it has been the story of nature's tinkering: of repeated evolutionary experiments. Our biological history has been one of sporadic events rather than gradual accretions. Over the past five million years, new hominid species have regularly emerged, competed, coexisted, colonized new environments and succeeded—or failed. We have only the dimmest of perceptions of how this dramatic history of innovation and interaction unfolded, but it is already evident that our species, far from being the pinnacle of the hominid evolutionary tree, is simply one more of its many terminal twigs.

The Roots of Our Solitude

Although this is all true, *H. sapiens* embodies something that is undeniably unusual and is neatly captured by the fact that we are alone in the world today. Whatever that something is, it is related to how we interact with the external world: it is behavioral, which means that we have to look to our archaeological record to find evidence of it. This record begins some 2.5 million years ago with the production of the first recognizable stone tools: simple sharp flakes chipped from parent "cores." We don't know exactly who the inventor was, but chances are that he or she was something we might call an australopith.

This innovation represented a major cognitive leap and had profound long-term consequences for hominids. It also inaugurated a pattern of highly intermittent technological change. It was a full million years before the next significant technological innovation came along: the creation about 1.5 million years ago, probably by *H. ergaster*, of the hand axe. These symmetrical implements, shaped from large stone cores, were the first to conform to a "mental template" that existed in the toolmaker's mind. This template remained essentially unchanged for another million years or more, until the invention of "prepared-core" tools by *H. heidelbergensis* or a relative. Here a stone core was elaborately shaped in such a way that a single blow would detach what was an effectively finished implement.

Among the most accomplished practitioners of prepared-core technology were the large-brained, big-faced and low-skulled Neanderthals, who occupied Europe and western Asia until about 30,000 years ago. Because they left an excellent record of themselves and were abruptly replaced by modern humans who did the same, the Neanderthals furnish us with a particularly instructive yardstick by which to judge our own uniqueness. The stoneworking skills of the Neanderthals were impressive, if somewhat stereotyped, but they rarely if ever made tools from other preservable materials. And many archaeologists question the sophistication of their hunting skills.

Further, despite misleading early accounts of bizarre Neanderthal "bear cults" and other rituals, no substantial evidence has been found for symbolic behaviors among these hominids, or for the production of symbolic objects—certainly not before contact had been made with modern humans. Even the occasional Neanderthal practice of burying the dead may have been simply a way of discouraging hyena incursions into their living spaces, or have a similar mundane explanation, for Neanderthal burials lack the "grave goods" that would attest to ritual and belief in an afterlife. The Neanderthals, in other words, though admirable in many ways and for a long time successful in the difficult circumstances of the late Ice Ages, lacked the spark of creativity that, in the end, distinguished *H. sapiens*.

Although the source of *H. sapiens* as a physical entity is obscure, most evidence points to an African origin perhaps between 150,000 and 200,000 years ago. Modern behavior patterns did not emerge until much later. The best evidence comes from Israel and environs, where Neanderthals lived about 200,000 years ago or perhaps even earlier. By about 100,000 years ago, they had been joined by anatomically modern *H. sapiens*, and the remarkable thing is that the tools and sites the two hominid species left behind are essentially identical. As far as can be told, these two hominids behaved in similar ways despite their anatomical differences. And as long as they did so, they somehow contrived to share the Levantine environment.

The situation in Europe could hardly be more different. The earliest *H. sapiens* sites there date from only about 40,000 years ago, and just 10,000 or so years later the formerly ubiquitous Neanderthals were gone. Significantly, the *H. sapiens* who invaded Europe brought with them abundant evidence of a fully formed and unprecedented modern sensibility. Not only did they possess a new "Upper Paleolithic" stoneworking technology based on the production of multiple long, thin blades from cylindrical cores, but they made tools from bone and antler, with an exquisite sensitivity to the properties of these materials.

Even more significant, they brought with them art, in the form of carvings, engravings and spectacular cave paintings; they kept records on bone and stone plaques; they made music on wind instruments; they crafted elaborate personal adornments; they afforded some of their dead elaborate burials with grave goods (hinting at social stratification in addition to belief in an afterlife, for not all burials were equally fancy); their living sites were highly organized, with evidence of sophisticated hunting and fishing. The pattern of intermittent technological innovation was gone, replaced by constant refinement. Clearly, these people were *us*.

In all these ways, early Upper Paleolithic people contrasted dramatically with the Neanderthals. Some Neanderthals in Europe seem to have picked up new ways of doing things from the arriving *H. sapiens*, but we have no direct clues as to the nature of the interaction between the two species. In light of the Neanderthals' rapid disappearance, though, and of the appalling subsequent record of *H. sapiens*, we can reasonably surmise that such interactions were rarely happy for the former. Certainly the repeated pattern at archaeological sites is one of short-term replacement, and there is no convincing biological evidence of any intermixing in Europe.

In the Levant, the coexistence ceased—after about 60,000 years or so—at right about the time that Upper Paleolithic–like

tools began to appear. About 40,000 years ago the Neanderthals of the Levant yielded to a presumably culturally rich *H. sapiens,* just as their European counterparts had.

The key to the difference between the European and the Levantine scenarios lies, most probably, in the emergence of modern cognition—which, it is reasonable to assume, is equivalent to the advent of symbolic thought. Business had continued more or less as usual right through the appearance of modern bone structure, and only later, with the acquisition of fully modern behavior patterns, did *H. sapiens* become completely intolerant of competition from its nearest—and, evidently, not its dearest.

To understand how this change in sensibility occurred, we have to recall certain things about the evolutionary process. First, as in this case, all innovations must necessarily arise *within* preexisting species—for where else can they do so? And second, many novelties arise as "exaptations," features acquired in one context before (often long before) being coopted in a different one. For example, hominids possessed essentially modern vocal tracts for hundreds of thousands of years before the behavioral record gives us any reason to believe that they employed the articulate speech that the peculiar form of this tract permits. Finally, we need to bear in mind the phenomenon of emergence whereby a chance coincidence gives rise to something totally unexpected. The classic example here is water, whose properties are unpredicted by those of hydrogen and oxygen atoms alone.

If we combine these various observations we can see that, profound as the consequences of achieving symbolic thought may have been, the process whereby it came about was unexceptional. We have no idea at present how the modern human brain converts a mass of electrical and chemical discharges into what we experience as consciousness. We do know, however, that somehow our lineage passed to symbolic thought from some nonsymbolic precursor state. The only plausible possibility is that with the arrival of anatomically modern *H. sapiens,* existing exaptations were fortuitously linked by some relatively minor genetic innovation to create an unprecedented potential.

Yet even in principle this cannot be the full story, because anatomically modern humans behaved archaically for a long time before adopting modern behaviors. That discrepancy may be the result of the late appearance of some key hardwired innovation not reflected in the skeleton, which is all that fossilizes. But this seems unlikely, because it would have necessitated a wholesale Old World–wide replacement of hominid populations in a very short time, something for which there is no evidence.

It is much more likely that the modern human capacity was born at—or close to—the origin of *H. sapiens,* as an ability that lay fallow until it was activated by a cultural stimulus of some kind. If sufficiently advantageous, this behavioral novelty could then have spread rapidly by cultural contact among populations that already had the potential to acquire it. No population replacement would have been necessary.

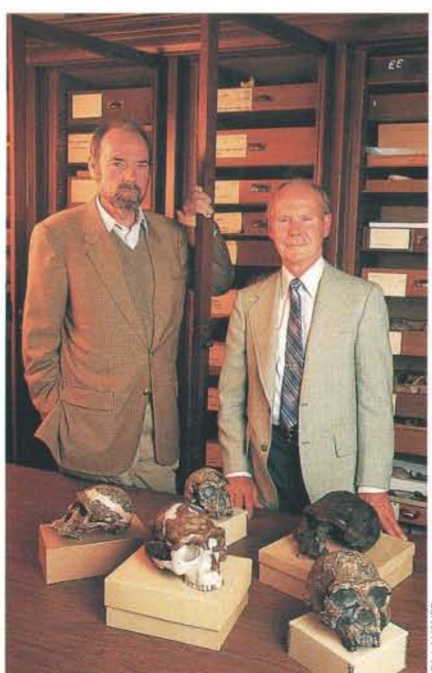
It is impossible to be sure what this innovation might have been, but the best current bet is that it was the invention of language. For language is not simply the medium by which we express our ideas and experiences to each other. Rather it is fundamental to the thought process itself. It involves categorizing and naming objects and sensations in the outer and inner worlds and making associations between resulting mental symbols. It is, in effect, impossible for us to conceive of thought (as we are familiar with it) in the absence of language, and it is the ability to form mental symbols that is the fount of our creativity, for only once we create such symbols can we recombine them and ask such questions as "What if...?"

We do not know exactly how language might have emerged in one local population of *H. sapiens,* although linguists have speculated widely. But we do know that a creature armed with symbolic skills is a formidable competitor—and not necessarily an entirely rational one, as the rest of the living world, including *H. neanderthalensis,* has discovered to its cost. SA

The Author and the Illustrator

IAN TATTERSALL and JAY H. MATTERNES have worked together since the early 1990s, notably on the Hall of Human Biology and Evolution at the American Museum of Natural History in New York City and at the Gunma Museum in Japan (where the Tuc mural on pages 40 and 41 is). Tattersall (*left in photograph*) was born in England and raised in East Africa. He is a curator in the department of anthropology at the American Museum of Natural History. His latest books include *Becoming Human: Evolution and Human Uniqueness* (Harcourt Brace, 1998) and *The Last Neanderthal: The Rise, Success, and Mysterious Extinction of Our Closest Human Relatives* (Westview, 1999, revised).

Matternes is an artist and sculptor who has for the past 40 years specialized in fossil primates and hominids. In addition to his museum murals, he is well known for his illustrations for books, periodicals and television, including Time/Life Books and *National Geographic*. The research for his depictions has taken him to many parts of the U.S., Canada, Mexico, France, Colombia and Africa.



ERICA LANSNER

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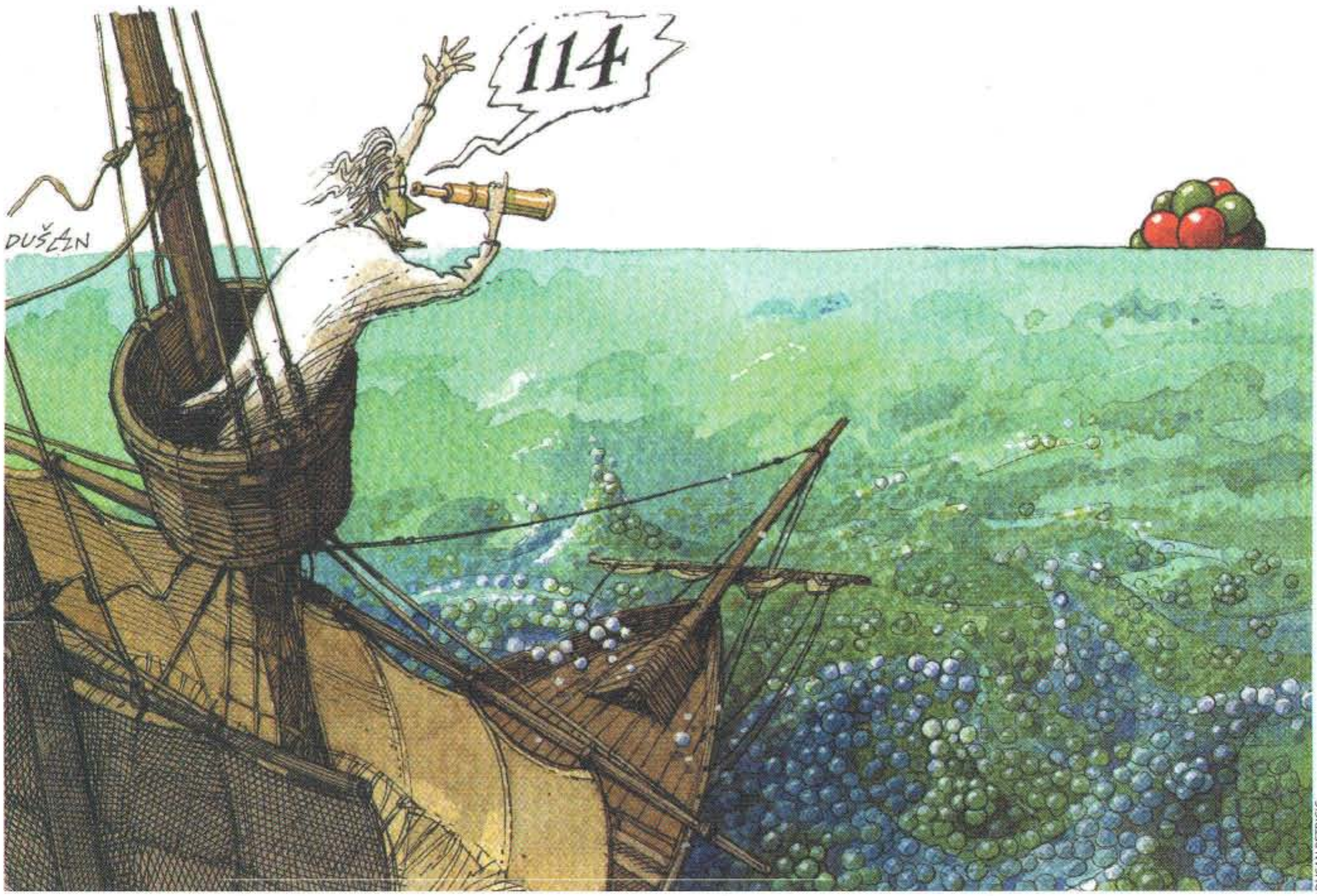
Voyage to SUPERHEAVY Island



DUSAN PETRICIC

The synthesis of element 114 confirmed decades-old theoretical predictions of a little patch of nuclear stability in a sea of short-lived superheavy nuclei

by Yuri Ts. Oganessian, Vladimir K. Utyonkov and Kenton J. Moody

The creation of the element neptunium in the spring of 1940 launched chemists on a fascinating journey into uncharted terrain. In this transuranic world, atoms whose nuclei have more than the 92 protons of a uranium nucleus exhibit unusual or unique properties. With their large numbers of electrons, these heavy elements have given chemists invaluable insights into the arrangement of electrons in atoms and into chemical bonding. The elements have also found uses in technologies ranging from nuclear weapons to smoke detectors.

So far this research has produced 23 new elements with atomic nuclei that have more protons than uranium atoms do. Of those 23, only the "lightest" two—neptunium and plutonium—exist at all in nature.

Recently the creation of element 114 marked the end of a difficult leg of the grand transuranic voyage. The passage was like a perilous crossing of a sea of instability made up of elements with more than 106 protons in their nuclei.

YURI GRIPAS *Gamma Liaison*

RESEARCH TEAM at the Joint Institute for Nuclear Research in Dubna, Russia, posed near its experimental setup; the mass separator is in the top left corner of the photograph, and the protruding arms of the target apparatus are visible toward the right. The group includes authors Utyonkov (*second from left*) and Oganessian (*fourth from left*).

By bombarding heavy nuclei with ion beams of lighter nuclei, scientists create superheavy nuclei that are so unstable that they split apart, oftentimes only a tiny fraction of a second after they are created. As they approached the "magic" number of 114, however, researchers found themselves coming to an island of stability where a collection of even heavier synthetic elements exhibit surprising stability and longevity.

Like the fabled city of El Dorado, the island of stability was long believed to exist but was considered impossible to reach; nuclear physicists had theorized about it as early as 1966. But unlike El Dorado, the whereabouts of the island of stability was no secret: its central, most stable point was predicted to be an isotope of element 114 with 184 neutrons, surrounded by neighboring but somewhat less stable elements between 109 and 115. Physicists knew exactly where they needed to go; the problems were how to get there and how to know when they had arrived.

The first attempts to synthesize an element occurred in 1934, when scientists began bombarding the nuclei of heavy elements with streams of neutrons. Each neutron captured by the target atom's nucleus underwent beta decay, changing into one proton and one electron, creating an element that had one more proton in its nucleus than the target nucleus had. In chemical terminology the created element had an atomic number that was greater, by one, than that of the target element. An element's atomic number is merely a tally of the protons in the nuclei of its atoms. The number defines an element and its place in the periodic table. Besides protons, atomic nuclei also contain neutrons, which carry no charge. All atoms of a single element must have the same number of protons, but different "isotopes" of the element have different numbers of neutrons and different degrees of stability.

By the mid-1950s researchers had produced elements 93, 94, 99 and 100 in this way. During the same period, they created elements 95, 96, 97, 98 and 101 by irradiating heavy nuclei with streams of alpha particles, which are helium nuclei, and boosted the atomic numbers two steps at a time.

The development of particle accelerators allowed scientists to direct high-intensity beams of ions of light elements such as boron (atomic number 5) at the nuclei of elements with atomic numbers between 94 and 98, to cause fusion of the two. For fusion to take place, the two nuclei must collide with enough energy to overcome the electrostatic force that causes the positively charged protons in each nucleus to repel each other. A great deal of energy is needed for this to occur, resulting in a new nucleus that is very hot. That heat, in turn, increases the likelihood that the new element will fission rather than "relax" into a stable state and remain intact. This technique yielded elements 102 through 106 between 1958 and 1974. Above 106, the tendency to fission made it impossible to synthesize new elements.

Then, in 1974, one of the authors (Oganessian) at the Joint Institute for Nuclear Research (JINR) in Dubna, Russia, discovered that using a beam of heavier ions to bombard lighter target nuclei could produce nuclei with lower excitation energies, allowing them to undergo fusion and remain intact. This is known as "cold fusion" but should not

be confused with the discredited process of the same name that was widely publicized during the 1980s. Active research using this approach began after the 1975 opening of the UNILAC (Universal Linear Accelerator) at the Society for Heavy Ion Research in Darmstadt, Germany, which can accelerate even very heavy ions at varying energies.

The decay properties of this isotope hint that the superheavy elements may be even more stable than predicted.

Unfortunately, because so few nuclei of the desired new elements are produced during an experiment, and because the "daughter" nuclei resulting from the decay of the new element themselves decay so quickly that they must be detected while the synthesis process is still under way, existing methods could not detect elements produced by this new technique. Thus, no new elements were identified for several years.

In the early 1980s a research team at the Darmstadt facility developed a sophisticated and sensitive method for identifying the new fusion nuclei and was able to synthesize elements 107, 108 and 109. The barriers to synthesis and detection were enormous—the researchers had to operate the UNILAC for two weeks to produce a single atom of element 109. Nevertheless, by further adjusting the intensity of the ion beam and enhancing the sensitivity of the sensing devices, the same team was able to produce element 111 in 1994 and element 112 in 1996. Element 112 has a half-life of 240 microseconds, and only two atoms of it were produced in 25 days.

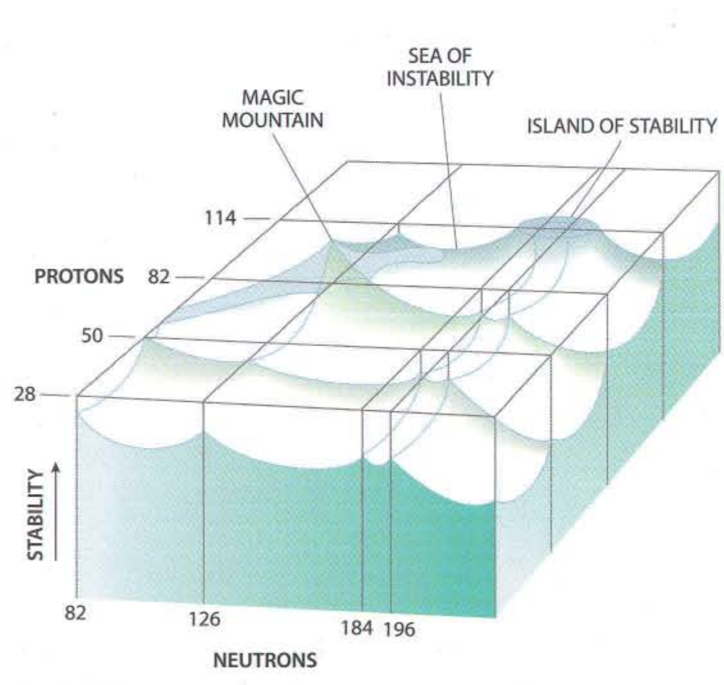
Since 1994, research groups in Germany, the U.S. and Russia have added six new elements to the periodic table, with atomic numbers as high as 118. The most important synthesis has been the production of isotopes of element 114, which has conclusively demonstrated the existence of the island of stability. Reaching the island is so significant because it demonstrates the theoretical prediction that certain "magic" numbers of protons and neutrons result in especially tightly bound nuclei, stable closed shells similar to the configurations of electrons associated with filled atomic orbital shells that give the noble gases their inert chemical behavior and define the periodicity and reactivity of the chemical elements.

The known magic numbers of the nuclear shell model, which occur at the element lead (82 protons and 126 neutrons), among other places in the periodic table, were derived as early as 1948. The prediction of the next magic numbers at 114 protons and 184 neutrons in 1966 contradicted prevailing theory: at that time, it was expected that the decay half-lives of synthesized elements, along with their stability against fission, would decrease catastrophically as their nuclei grew heavier. The prediction of the magic numbers gave rise to the speculation that there was an island of unusually long-lived nuclear species well out in the uncharted sea of instability.

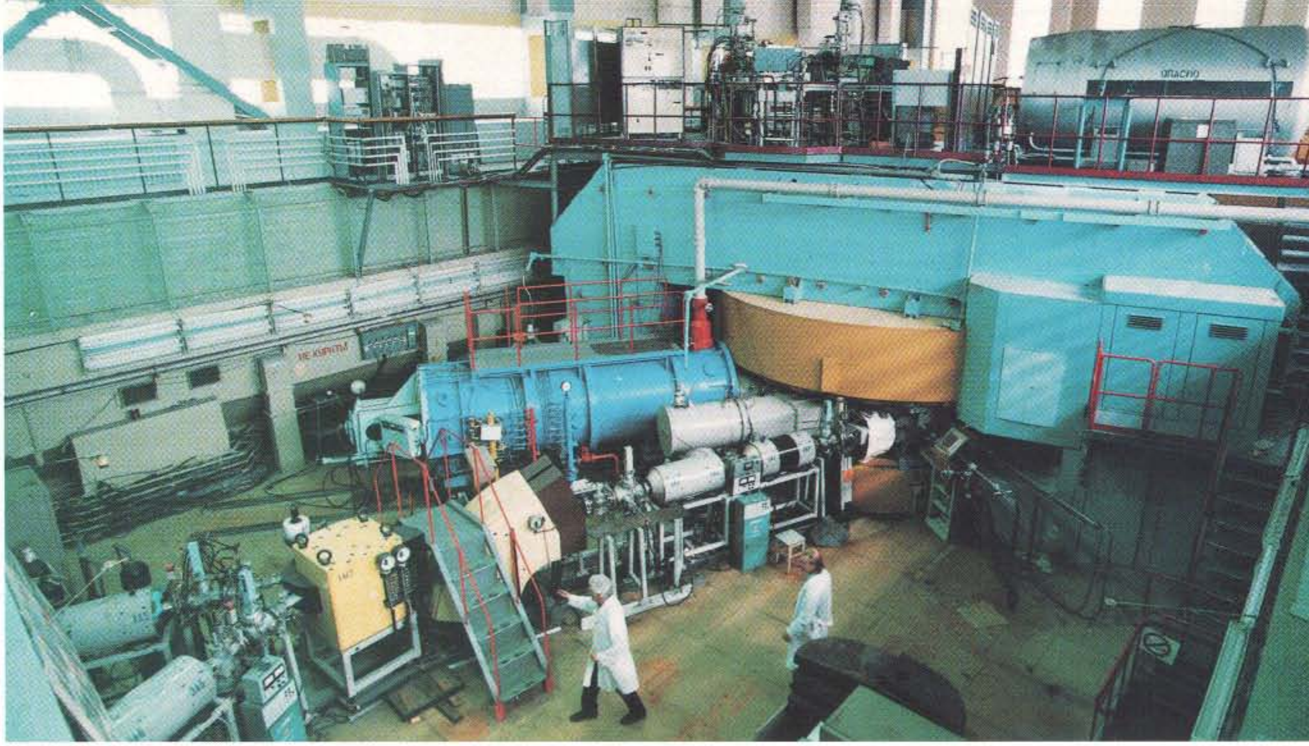
One reason the island is so difficult to reach is that these nuclei have more neutrons per proton than any known stable nuclei. We chose a reaction that introduced the most neutrons into the synthesized nuclei: irradiating Pu-244 (plutonium 244)—the exotic heaviest isotope of plutonium—with an intense stream of ions of Ca-48 (calcium 48)—a rare and expensive neutron-rich isotope of calcium. Our expectation was that the fusion would result in a compound nucleus with 114 protons and 178 neutrons. Such an isotope would be as close as possible to the doubly magic configuration of 114 protons and 184 neutrons.

We knew that if the Ca-48 and Pu-244 nuclei collided with enough energy to overcome their mutual electrostatic repulsion, the excitation energy of the

LAURIE GRACE



OCEAN OF LARGE NUCLEI contains many unstable specimens, or isotopes. An element's atomic nucleus has a set number of protons but typically has a variety of versions, called isotopes, each with a different number of neutrons and degree of stability. For nuclei with upward of 106 protons, especially, many of these isotopes are relatively unstable and are like a "sea of instability." In this metaphor, an unusually stable isotope of lead, with 82 protons and 126 neutrons, is a kind of magic mountain. And since 1966 researchers have theorized about an island of stability, at the center of which would be an isotope with 114 protons and 184 neutrons. Chemists recently reached the shores of the island by creating an isotope with 114 protons and 175 neutrons.



YURI GRIPAS *Gamma Liaison*

resulting compound nuclei would be low enough that at least some of them would not fission, because the evaporation of three neutrons—resulting in an isotope of element 114 with 175 neutrons—would cool the new nuclei below the fission barrier.

How We Did It

Previous searches for superheavy elements using similar reactions were unsuccessful because as few as one of these nuclei is produced over a period of a few weeks amid a background of trillions of other nuclear species. By increasing the sensitivity of our detection method by hundreds of times over those used in previous attempts, we were able to detect the newly synthesized elements before they decayed.

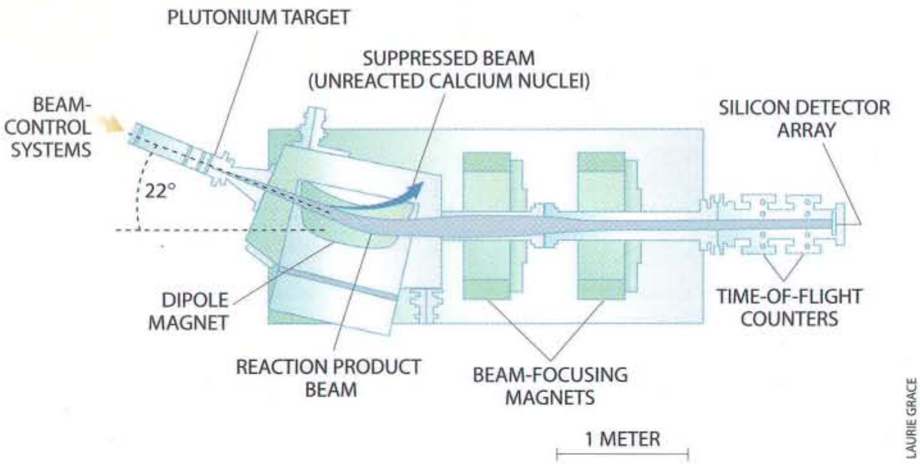
We performed our experiment at the heavy-ion cyclotron at JINR. Ions of Ca-48 were accelerated to approximately one tenth the speed of light and beamed at the target, which consisted of several milligrams of Pu-244 electroplated onto thin titanium foils.

To detect the new fusion nuclei we were trying to synthesize, we needed a means of separating the products in which we were interested from all others produced by the experiment. The expected signature of the decay of our superheavy nucleus would be a series of alpha decays as element 114 decays to element 112, which decays to element 110, which decays to element 108, until the island of stability is left behind and spontaneous fission occurs. Unfortunately, the alpha decay and fission rates from the decays of unwanted nuclei also generated by the experiment can produce sequences of random events that can mimic the decay sequence of element 114. Billions of these unwanted nuclei are produced per second, whereas the expected production rate for the element 114 isotope is far less than one atom per day. Consequently, it is vitally important to suppress these unwanted background reactions so as to recognize the element 114 reaction when it occurs.

To do this, the scientists at Dubna devised a gas-filled separator, which gave us effective transmission of the products we were seeking and very efficient detection of the radioactive decay sequences that would reveal their presence; it also effectively suppressed unwanted products. Heavy-ion fusion products (a mixture of the synthesized 114 nuclei and other fusion products) recoil from the target and enter a chamber filled with low-pressure hydrogen gas, which is confined between the pole faces of a dipole magnet. The recoiling heavy ions interact with the hydrogen gas atoms, and those whose electrons are bound to their nuclei with less energy than that supplied by the collision tend to be lost. The magnetic field is adjusted so that only the nuclei of interest will arrive at the detector array. Unreacted beam particles of Ca-48 pass into the hydrogen at high velocity and are so highly ionized that the magnetic field diverts them from the path of the particles we are seeking. The gas-filled separator also strongly suppresses other unwanted products of peripheral nuclear reactions.

Reaction products leaving the dipole magnets are focused with a set of magnetic quadrupoles, then pass through a time-of-flight (TOF) counter and bury themselves in a position-sensitive detector. The signal from the TOF counter enabled us to distinguish between the impact of products passing through the separator and the radioactive decay of products that are already implanted in the detector. The flight time through the TOF counter can be used to discriminate between low and high atomic numbers. In addition, the position-sensitive detector lowered the rate of background interference because

Only one atom of the new superheavy element was made in 40 days of irradiation.



DUBNA LABORATORY (*left*) creates beams that move from right to left in this photograph. To the left of this view was the gas-filled mass separator (*above*). Beams of reaction products from the plutonium target are bent by the dipole magnet; nuclei of interest are directed to an array of tiny silicon detectors. Researchers associate nuclear decays there with positions to determine which isotopes were created at the target.

it allowed us to identify and ignore unwanted reactions. All of these capabilities permitted us to detect and measure the element 114 nuclei we sought.

We performed our first experiment over a period of 40 days in November and December of 1998. During that time, we observed the signals of a total of three spontaneous fission decays, indicating that three synthesized compound nuclei had been created and had passed through the separator before fissioning. Two of them lasted about one millisecond each and were unwanted reactions caused by the decay of the nucleus of Am-244 (americium 244). Only one of these events (one atom in 40 days of irradiation!) involved an implant in the detector followed by three alpha decays (the successive loss of two protons and two neutrons, each loss resulting in decay to a lesser element with a lower atomic number), all occurring at the same position in the detector array.

This is exactly the decay signature we had expected: the relations between the decay energies and the decay times were consistent with what had been theorized for the decay of an isotope of element 114 and its resulting daughter elements. The flight time of the initial recoil nucleus and its implantation energy in the detector were also consistent with predictions, and the random rates in the detector indicate less than a 1 percent chance that the event was caused by random correlations of background events.

The Decay Chain

The isotope of element 114 with 175 neutrons has a half-life of 30.4 seconds. It decays to element 112; 112, with a half-life of 15.4 minutes, decays to element 110; 110, with a half-life of 1.6 minutes, then decays to element 108. The element 108 isotope, with 169 neutrons, is off the edge of the island of stability and decays by spontaneous fission. A subsequent experiment performed at Dubna produced a lighter isotope of element 114 with 173 neutrons, which is closer to the edge of the island of stability. This lighter isotope has a half-life of about five seconds and then undergoes alpha decay into its daughter nucleus, element 112; the daughter nucleus decays by spontaneous fission in three minutes.

We have confirmed the existence of the island of stability and have a measure of the magnitude of its effect. The lifetime of our element 114 isotope with 175 neutrons is more than 1,000 times longer than the lifetime of the 174-neutron isotope, which is produced as part of the decay chain from element 118 and was recently discovered at Lawrence Berkeley National Laboratory. Our isotope of element 112 with 173 neutrons is more than a million times longer-lived than the isotope with 165 neutrons, discovered in Darmstadt in 1996. These longer half-lives of our synthesized fusion products make it far easier to study them, and such studies may change the way we look at the fundamental properties of matter.

Recently we also created the isotope of element 114 that has 174 neutrons (so far we have made a grand total of two atoms of it). The decay properties of this isotope suggest, tantalizingly, that the superheavy elements may be even more stable than predicted by theory. Based on our experiment and the work of others, the future looks bright for the study of the limits of nuclear stability, with many prospects for new research and unexpected discoveries. With a concerted effort, we may even be able to solve for element 114 one of the traditional and most challenging difficulties of superheavy-element synthesis: finding a name for the new element that all interested parties can agree on! SA

The Authors

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Further Information

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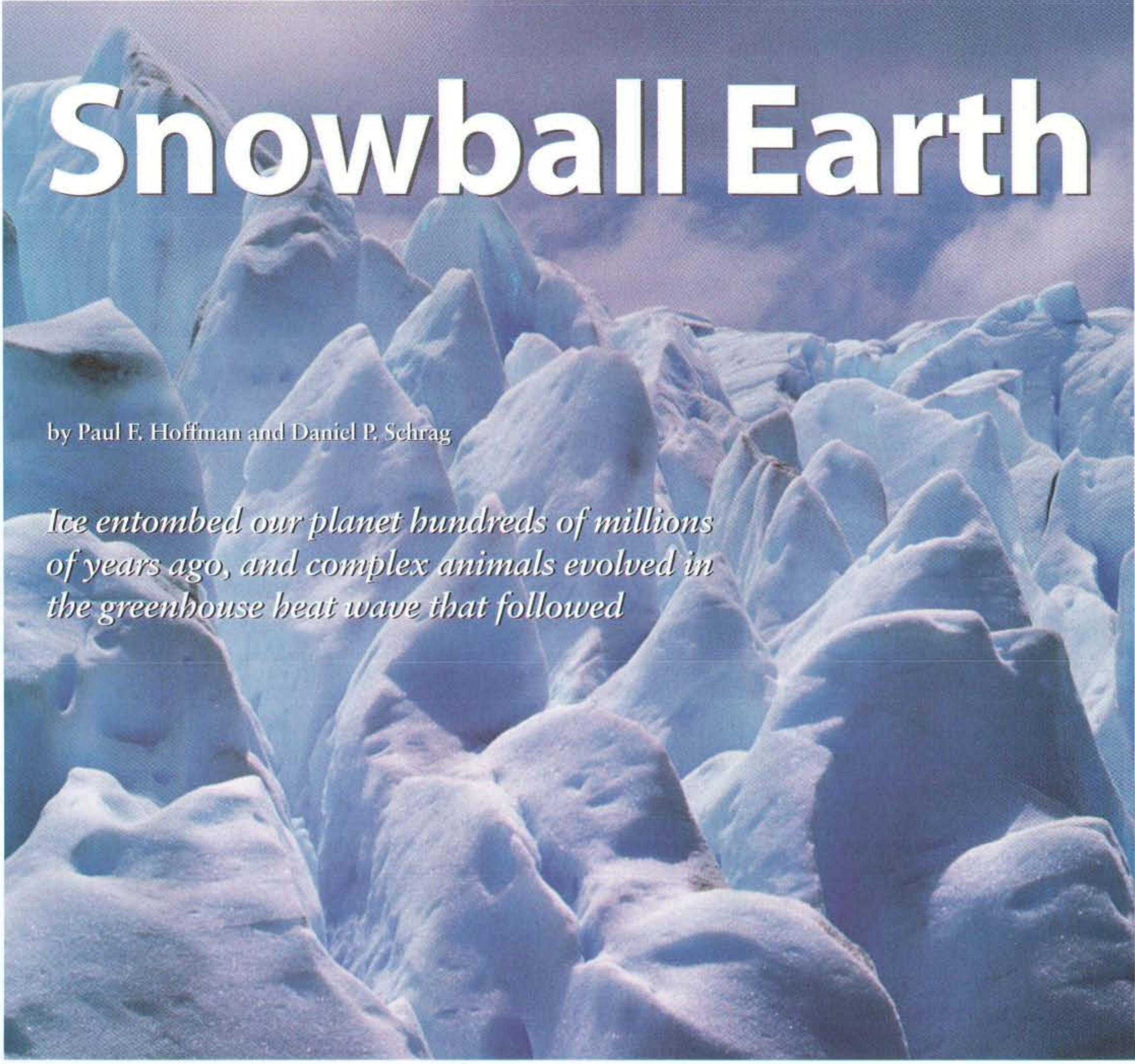

Snowball Earth

by Paul F. Hoffman and Daniel P. Schrag

Ice entombed our planet hundreds of millions of years ago, and complex animals evolved in the greenhouse heat wave that followed

Our human ancestors had it rough. Saber-toothed cats and woolly mammoths may have been day-to-day concerns, but harsh climate was a consuming long-term challenge. During the past million years, they faced one ice age after another. At the height of the last icy episode, 20,000 years ago, glaciers more than two kilometers thick gripped much of North America and Europe. The chill delivered ice as far south as New York City.

Dramatic as it may seem, this extreme climate change pales in comparison to the catastrophic events that some of our earliest microscopic ancestors endured around 600 million years ago. Just before the appearance of recognizable animal life, in a time period known as the Neoproterozoic, an ice age prevailed with such intensity that even the tropics froze over.

Imagine the earth hurtling through space like a cosmic snowball for 10 million years or more. Heat escaping from the molten core prevents the oceans from freezing to the bottom, but ice grows a kilometer thick in the –50 degree Celsius cold. All but a tiny fraction of the planet's primitive organisms die. Aside from grinding glaciers and groaning sea ice, the only stir comes from a smattering of volcanoes forcing their hot heads above the frigid surface. Although it seems the planet might never wake from its cryogenic slumber, the volcanoes slowly manufacture an escape from the chill: carbon dioxide.

With the chemical cycles that normally consume carbon dioxide halted by the frost, the gas accumulates to record levels. The heat-trapping capacity of carbon dioxide—a greenhouse gas—warms the planet and begins to melt the ice. The thaw takes only a few hundred years, but a new problem arises in the meantime: a brutal greenhouse effect. Any creatures that survived the icehouse must now endure a hothouse.

As improbable as it may sound, we see clear evidence that this striking climate reversal—the most extreme imaginable on this planet—happened as many as four times between 750 million and 580 million years ago. Scientists long presumed that the earth's climate was never so severe; such intense climate change has been more widely accepted for other planets such as Venus [see "Global Climate Change on Venus," by

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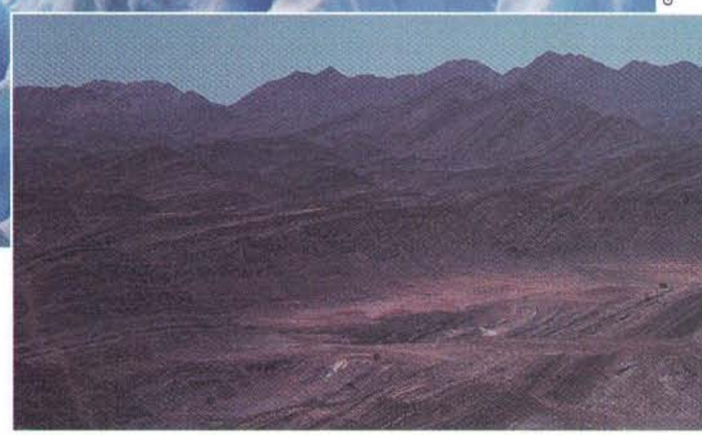


COURTESY OF PAUL F. HOFFMAN

TOWERS OF ICE **like Argentina's Moreno Glacier (*above*) once buried the earth's continents. Clues about this frozen past have surfaced in layers of barren rock such as these hills near the coast of northwest Namibia (*inset*).**

Mark A. Bullock and David H. Grinspoon; SCIENTIFIC AMERICAN, March 1999]. Hints of a harsh past on the earth began cropping up in the early 1960s, but we and our colleagues have found new evidence in the past eight years that has helped us weave a more explicit tale that is capturing the attention of geologists, biologists and climatologists alike.

Thick layers of ancient rock hold the only clues to the climate of the Neoproterozoic. For decades, many of those clues appeared rife with contradiction. The first paradox was the occurrence of glacial debris near sea level in the tropics. Glaciers near the equator today survive only at 5,000 meters above sea level or higher, and at the worst of the last ice age they reached no lower than 4,000 meters. Mixed in with the glacial debris are unusual deposits of iron-rich rock. These deposits should have been able to form only if the Neoproterozoic oceans and atmosphere contained little or no oxygen, but by that time the atmosphere had already evolved to nearly the same mixture of gases as it has today. To confound matters, rocks known to form in warm water seem to have accumulated just after the glaciers receded. If the earth were ever cold enough to ice over completely, how did it warm up again? In addition, the carbon isotopic signature in the rocks hinted at a prolonged drop in biological productivity. What could have caused this dramatic loss of life?

Each of these long-standing enigmas suddenly makes sense when we look at them as key plot developments in the tale of a "snowball earth." The theory has garnered cautious support in the scientific community since we first introduced the

HEIDI NOLAND

EARTH'S LANDMASSES **were most likely clustered near the equator during the global glaciations that took place around 600 million years ago. Although the continents have since shifted position, relics of the debris left behind when the ice melted are exposed at dozens of points on the present land surface, including what is now Namibia (*red dot*).**

idea in the journal *Science* a year and a half ago. If we turn out to be right, the tale does more than explain the mysteries of Neoproterozoic climate and challenge long-held assumptions about the limits of global change. These extreme glaciations occurred just before a rapid diversification of multicellular life, culminating in the so-called Cambrian explosion between 575 and 525 million years ago. Ironically, the long periods of isolation and extreme environments on a snowball earth would most likely have spurred on genetic change and could help account for this evolutionary burst.

The search for the surprisingly strong evidence for these climatic events has taken us around the world. Although we are now examining Neoproterozoic rocks in Australia, China, the western U.S. and the Arctic islands of Svalbard, we began our investigations in 1992 along the rocky cliffs of Namibia's Skeleton Coast. In Neoproterozoic times, this region of southwestern Africa was part of a vast, gently subsiding continental shelf located in low southern latitudes.

There we see evidence of glaciers in rocks formed from deposits of dirt and debris left behind when the ice melted. Rocks dominated by calcium- and magnesium-carbonate minerals lie just above the glacial debris and harbor the chemical evidence of the hothouse that followed. After hundreds of millions of years of burial, these now exposed rocks tell the story that scientists first began to piece together 35 years ago.

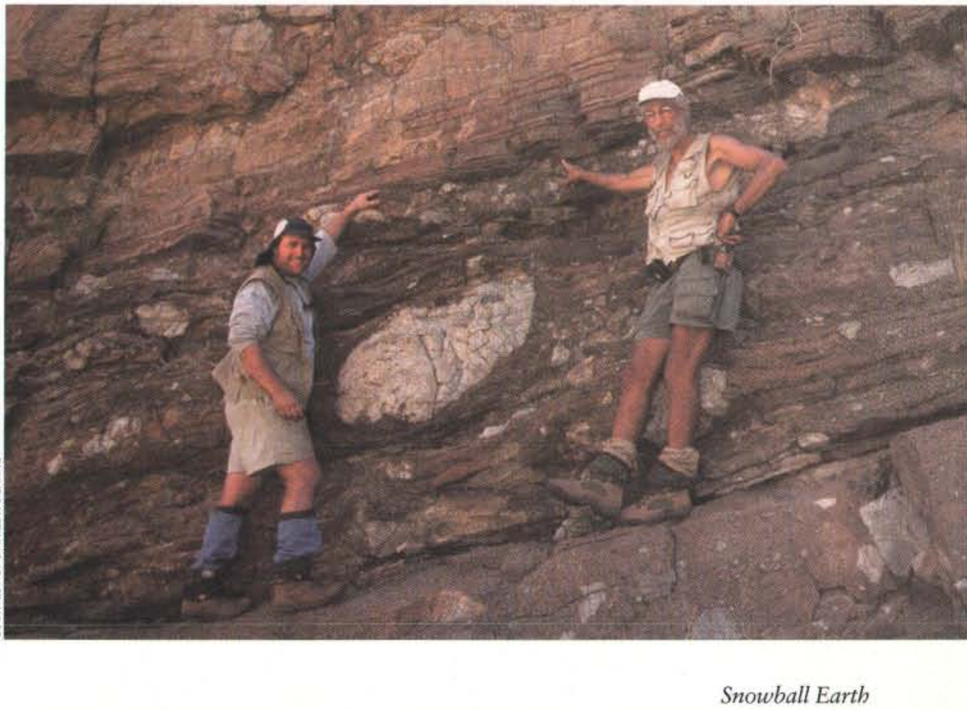
In 1964 W. Brian Harland of the University of Cambridge pointed out that glacial deposits dot Neoproterozoic rock outcrops across virtually every continent. By the early 1960s scientists had begun to accept the idea of plate tectonics, which describes how the planet's thin, rocky skin is broken into giant pieces that move atop a churning mass of hotter rock below. Harland suspected that the continents had clustered together near the equator in the Neoproterozoic, based on the magnetic orientation of tiny mineral grains in the glacial rocks. Before the rocks hardened, these grains aligned themselves with the magnetic field and dipped only slightly relative to horizontal because of their position near the equator. (If they had formed near the poles, their magnetic orientation would be nearly vertical.)

Realizing that the glaciers must have covered the tropics, Harland became the first geologist to suggest that the earth had experienced a great Neoproterozoic ice age [see "The Great Infra-Cambrian Glaciation," by W. B. Harland and M.J.S. Rudwick; Scientific American, August 1964]. Although some of Harland's contemporaries were skeptical about the reliability of the magnetic data, other scientists have since shown that Harland's hunch was correct. But no one was able to find an explanation for how glaciers could have survived the tropical heat.

At the time Harland was announcing his ideas about Neoproterozoic glaciers, physicists were developing the first mathematical models of the earth's climate. Mikhail Budyko of the Leningrad Geophysical Observatory found a way to explain tropical glaciers using equations that describe the way solar radiation interacts with the earth's surface and atmosphere to control climate. Some geographic surfaces reflect more of the sun's incoming energy than others, a quantifiable characteristic known as albedo. White snow reflects the most solar energy and has a high albedo, darker-colored seawater has a low albedo, and land surfaces have intermediate values that depend on the types and distribution of vegetation.

The more radiation the planet reflects, the cooler the temperature. With their high albedo, snow and ice cool the atmosphere and thus stabilize their own existence. Budyko knew that this phe-

COURTESY OF DANIEL P. SCHRAG



nomenon, called the ice-albedo feedback, helps modern polar ice sheets to grow. But his climate simulations also revealed that this feedback can run out of control. When ice formed at latitudes lower than around 30 degrees north or south of the equator, the planet's albedo began to rise at a faster rate because direct sunlight was striking a larger surface area of ice per degree of latitude. The feedback became so strong in his simulation that surface temperatures plummeted and the entire planet froze over.

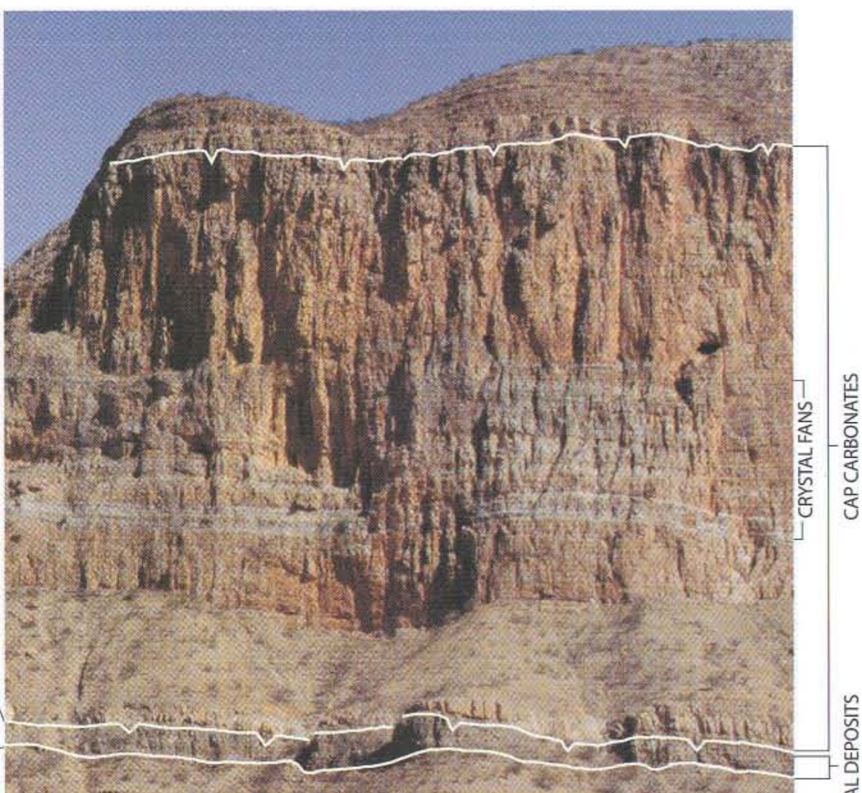
Frozen and Fried

Budyko's simulation ignited interest in the fledgling science of climate modeling, but even he did not believe the earth could have actually experienced a runaway freeze. Almost everyone assumed that such a catastrophe would have extinguished all life, and yet signs of microscopic algae in rocks up to one billion years old closely resemble modern forms and imply a continuity of life. Also, once the earth had entered a deep freeze, the high albedo of its icy veneer would have driven surface temperatures so low that it seemed there would have been no means of escape. Had such a glaciation occurred, Budyko and others reasoned, it would have been permanent.

The first of these objections began to fade in the late 1970s with the discovery of remarkable communities of organisms living in places once thought too harsh to harbor life. Seafloor hot springs support microbes that thrive on chemicals rather than sunlight. The kind of volcanic activity that feeds the hot springs would have continued unabated in a snowball earth. Survival prospects seem even rosier for psychrophilic, or cold-loving, organisms of the kind living today in the intensely cold and dry mountain valleys of East Antarctica. Cyanobacteria and certain kinds of algae occupy habitats such as snow, porous rock and the surfaces of dust particles encased in floating ice.

The key to the second problem—reversing the runaway freeze—is carbon dioxide. In a span as short as a human lifetime, the amount of carbon dioxide in the atmosphere can change as plants consume the gas for photosynthesis and as animals breathe it out during respiration. Moreover, human activities such as burning fossil fuels have rapidly loaded the air with carbon dioxide since the beginning of the Industrial Revolution in the late 1700s. In the earth's lifetime, however, these carbon sources and sinks become irrelevant compared with geologic processes.

Carbon dioxide is one of several gases emitted from volcanoes. Normally this endless supply of carbon is offset by the erosion of silicate rocks: The chemical breakdown of the rocks converts carbon dioxide to bicarbonate, which is washed to the oceans. There bicarbonate combines with calcium and magnesium ions to produce carbonate sediments, which store a great deal of carbon [see "Modeling the Geo-



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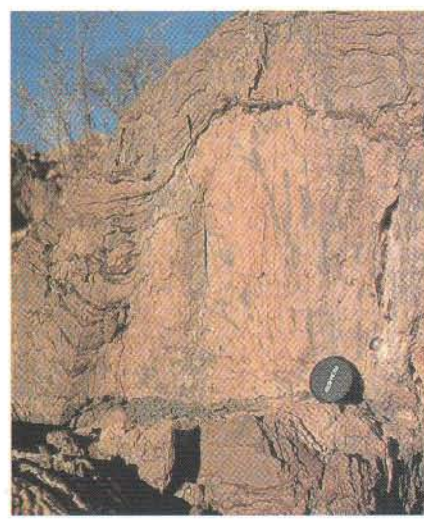


COURTESY OF DANIEL P. SCHRAG

ROCKY CLIFFS along Namibia's Skeleton Coast (*left*) have provided some of the best evidence for the snowball earth hypothesis. Authors Schrag (*far left*) and Hoffman point to a rock layer that represents the abrupt end of a 700-million-year-old snowball event. The light-colored boulder in the rock between them probably once traveled within an iceberg and fell to the muddy seafloor when the ice melted. Pure carbonate layers stacked above the glacial deposits precipitated in the warm, shallow seas of the hothouse aftermath. These "cap" carbonates are the only Neoproterozoic rocks that exhibit large crystal fans, which accompany rapid carbonate accumulation (*above*).

chemical Carbon Cycle," by R. A. Berner and A. C. Lasaga; SCIENTIFIC AMERICAN, March 1989].

In 1992 Joseph L. Kirschvink, a geobiologist at the California Institute of Technology, pointed out that during a global glaciation, an event he termed a snowball earth, shifting tectonic plates would continue to build volcanoes and to supply the atmosphere with carbon dioxide. At the same time, the liquid water needed to erode rocks and bury the carbon would be trapped in ice. With nowhere to go, carbon dioxide would collect to incredibly high levels—high enough, Kirschvink proposed, to heat the planet and end the global freeze.

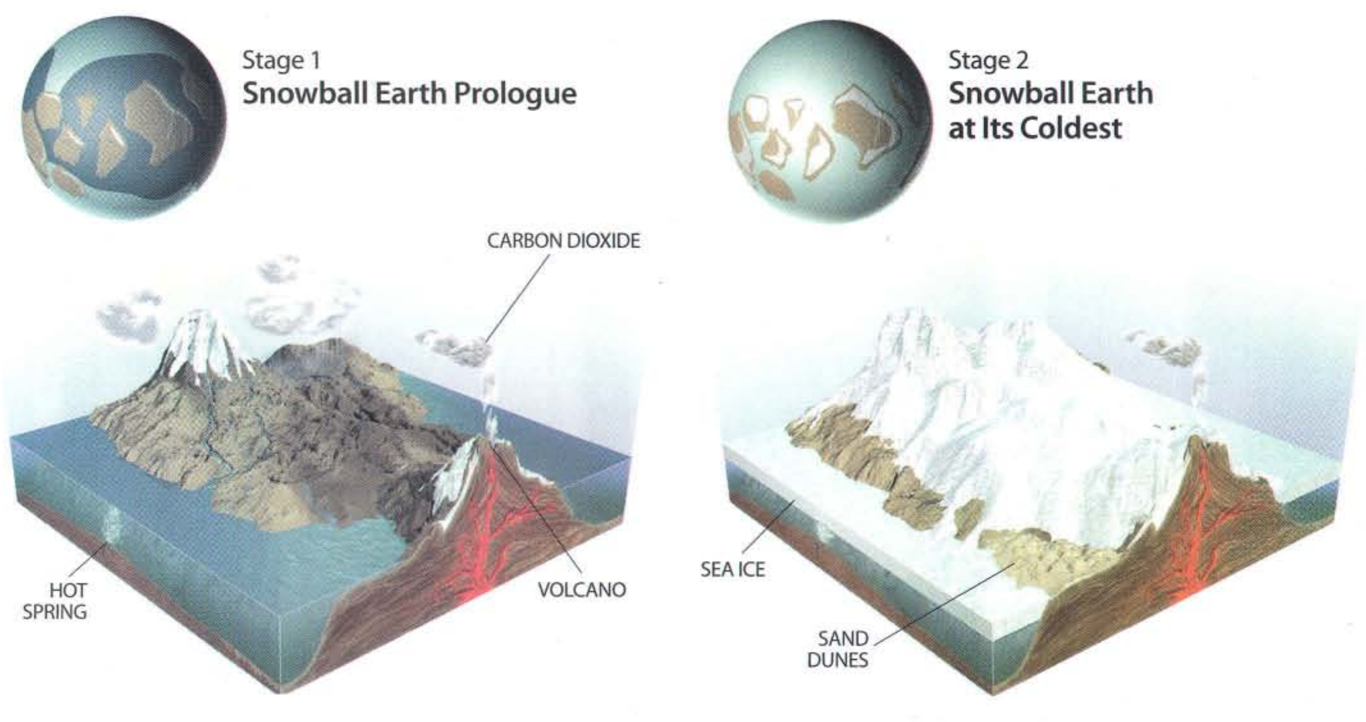
Kirschvink had originally promoted the idea of a Neoproterozoic deep freeze in part because of mysterious iron deposits found mixed with the glacial debris. These rare deposits are found much earlier in earth history when the oceans (and atmosphere) contained very little oxygen and iron could readily dissolve. (Iron is virtually insoluble in the presence of oxygen.) Kirschvink reasoned that millions of years of ice cover would deprive the oceans of oxygen, so that dissolved iron expelled from seafloor hot springs could accumulate in the water. Once a carbon dioxide–induced greenhouse effect began melting the ice, oxygen would again mix with the seawater and force the iron to precipitate out with the debris once carried by the sea ice and glaciers.

With this greenhouse scenario in mind, climate modelers Kenneth Caldeira of Lawrence Livermore National Laboratory and James F. Kasting of Pennsylvania State University estimated in 1992 that overcoming the runaway freeze would require roughly 350 times the present-day concentration of carbon dioxide. Assuming volcanoes of the Neoproterozoic belched out gases at the same rate as they do today, the planet would have remained locked in ice for up to tens of millions of years before enough carbon dioxide could accumulate to begin melting the sea ice. A snowball earth would be not only the most severe conceivable ice age, it would be the most prolonged.

Carbonate Clues

Kirschvink was unaware of two emerging lines of evidence that would strongly support his snowball earth hypothesis. The first is that the Neoproterozoic glacial deposits are almost everywhere blanketed by carbonate rocks. Such rocks typically form in warm, shallow seas, such as the Ba-

EVOLUTION OF A SNOWBALL EARTH EVENT . . .



Breakup of a single landmass 770 million years ago leaves small continents scattered near the equator. Formerly landlocked areas are now closer to oceanic sources of moisture. Increased rainfall scrubs more heat-trapping carbon dioxide out of the air and erodes continental rocks more quickly. Consequently, global temperatures fall, and large ice packs form in the polar oceans. The white ice reflects more solar energy than does darker seawater, driving temperatures even lower. This feedback cycle triggers an unstoppable cooling effect that will engulf the planet in ice within a millennium.

Average global temperatures plummet to –50 degrees Celsius shortly after the runaway freeze begins. The oceans ice over to an average depth of more than a kilometer, limited only by heat emanating slowly from the earth's interior. Most microscopic marine organisms die, but a few cling to life around volcanic hot springs. The cold, dry air arrests the growth of land glaciers, creating vast deserts of windblown sand. With no rainfall, carbon dioxide emitted from volcanoes is not removed from the atmosphere. As carbon dioxide accumulates, the planet warms and sea ice slowly thins.

hama Banks in what is now the Atlantic Ocean. If the ice and warm water had occurred millions of years apart, no one would have been surprised. But the transition from glacial deposits to these "cap" carbonates is abrupt and lacks evidence that significant time passed between when the glaciers dropped their last loads and when the carbonates formed. Geologists were stumped to explain so sudden a change from glacial to tropical climates.

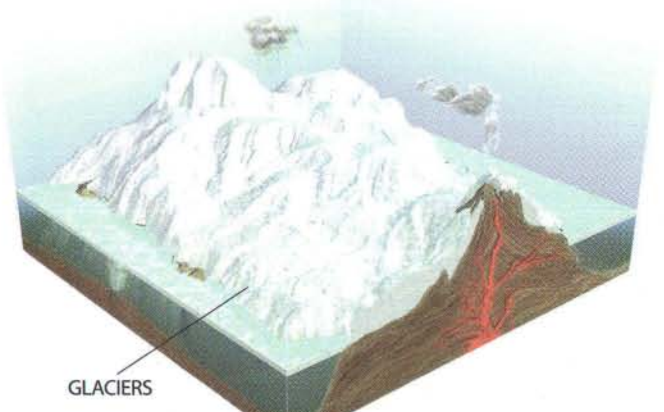
Pondering our field observations from Namibia, we realized that this change is no paradox. Thick sequences of carbonate rocks are the expected consequence of the extreme greenhouse conditions unique to the transient aftermath of a snowball earth. If the earth froze over, an ultrahigh carbon dioxide atmosphere would be needed to raise temperatures to the melting point at the equator. Once melting begins, low-albedo seawater replaces high-albedo ice and the runaway freeze is reversed [*see illustration below*]. The greenhouse atmosphere helps to drive surface temperatures upward to almost 50 degrees C, according to calculations made last summer by climate modeler Raymond T. Pierrehumbert of the University of Chicago.

Resumed evaporation also helps to warm the atmosphere because water vapor is a powerful greenhouse gas, and a swollen reservoir of moisture in the atmosphere would drive an enhanced water cycle. Torrential rain would scrub some of the carbon dioxide out of the air in the form of carbonic acid, which would rapidly erode the rock debris left bare as the glaciers subsided. Chemical erosion products would quickly build up in the ocean water, leading to the precipitation of carbonate sediment that would rapidly accumulate on the seafloor and later become rock. Structures preserved in the Namibian cap carbonates indicate that they accumulated extremely rapidly, perhaps in only a few thousand years. For example, crystals of the mineral aragonite, clusters of which are as tall as a person, could precipitate only from seawater highly saturated in calcium carbonate.

Cap carbonates harbor a second line of evidence that supports Kirschvink's snowball escape scenario. They contain an unusual pattern in the ratio of two isotopes of carbon: common carbon 12 and rare carbon 13, which has an extra neutron in its nucleus. The same patterns are observed in cap carbonates worldwide, but no one thought to interpret them in terms of a snowball earth. Along with Alan Jay Kaufman,

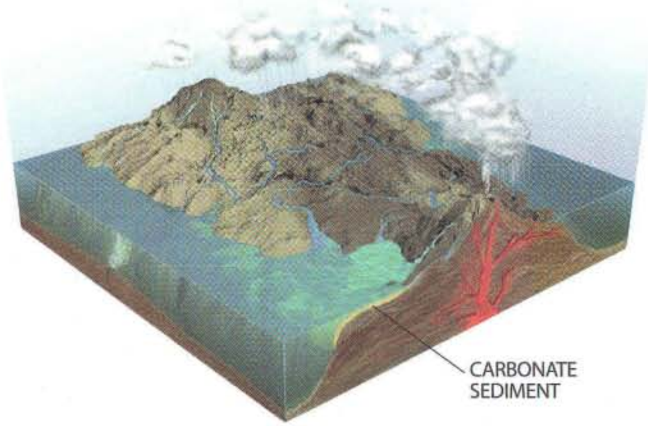
… AND ITS HOTHOUSE AFTERMATH

Stage 3
Snowball Earth as It Thaws



Concentrations of carbon dioxide in the atmosphere increase 1,000-fold as a result of some 10 million years of normal volcanic activity. The ongoing greenhouse warming effect pushes temperatures to the melting point at the equator. As the planet heats up, moisture from sea ice sublimating near the equator refreezes at higher elevations and feeds the growth of land glaciers. The open water that eventually forms in the tropics absorbs more solar energy and initiates a faster rise in global temperatures. In a matter of centuries, a brutally hot, wet world will supplant the deep freeze.

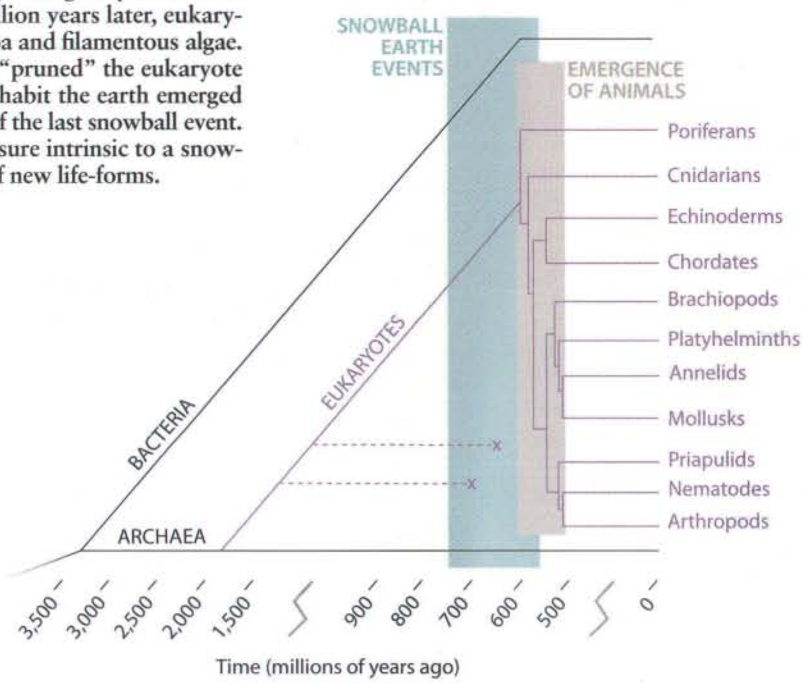
Stage 4
Hothouse Aftermath



As tropical oceans thaw, seawater evaporates and works along with carbon dioxide to produce even more intense greenhouse conditions. Surface temperatures soar to more than 50 degrees Celsius, driving an intense cycle of evaporation and rainfall. Torrents of carbonic acid rain erode the rock debris left in the wake of the retreating glaciers. Swollen rivers wash bicarbonate and other ions into the oceans, where they form carbonate sediment. New life-forms—engendered by prolonged genetic isolation and selective pressure—populate the world as global climate returns to normal.

DAVID FIERSTEIN

ALL ANIMALS **descended from the first eukaryotes, cells with a membrane-bound nucleus, which appeared about two billion years ago. By the time of the first snowball earth episode more than one billion years later, eukaryotes had not developed beyond unicellular protozoa and filamentous algae. But despite the extreme climate, which may have "pruned" the eukaryote tree (*dashed lines*), all 11 animal phyla ever to inhabit the earth emerged within a narrow window of time in the aftermath of the last snowball event. The prolonged genetic isolation and selective pressure intrinsic to a snowball earth could be responsible for this explosion of new life-forms.**



HEIDI NOLAND

an isotope geochemist now at the University of Maryland, and Harvard University graduate student Galen Pippa Halverson, we have discovered that the isotopic variation is consistent over many hundreds of kilometers of exposed rock in northern Namibia.

Carbon dioxide moving into the oceans from volcanoes is about 1 percent carbon 13; the rest is carbon 12. If the formation of carbonate rocks were the only process removing carbon from the oceans, then the rock would have the same fraction of carbon 13 as that which comes out of volcanoes. But the soft tissues of algae and bacteria growing in seawater also use carbon from the water around them, and their photosynthetic machinery prefers carbon 12 to carbon 13. Consequently, the carbon that is left to build carbonate rocks in a life-filled ocean such as we have today has a higher ratio of carbon 13 to carbon 12 than does the carbon fresh out of a volcano.

The carbon isotopes in the Neoproterozoic rocks of Namibia record a different situation. Just before the glacial deposits, the amount of carbon 13 plummets to levels equivalent to the volcanic source, a drop we think records decreasing biological productivity as ice encrusted the oceans at high latitudes and the earth teetered on the edge of a runaway freeze. Once the oceans iced over completely, productivity would have essentially ceased, but no carbon record of this time interval exists because calcium carbonate could not have formed in an ice-covered ocean. This drop in carbon 13 persists through the cap carbonates atop the glacial deposits and then gradually rebounds to higher levels of carbon 13 several hundred meters above, presumably recording the recovery of life at the end of the hothouse period.

Abrupt variation in this carbon isotope record shows up in carbonate rocks that represent other times of mass extinction, but none are as large or as long-lived. Even the meteorite impact that killed off the dinosaurs 65 million years ago did not bring about such a prolonged collapse in biological activity.

Overall, the snowball earth hypothesis explains many extraordinary observations in the geologic record of the Neoproterozoic world: the carbon isotopic variations associated with the glacial deposits, the paradox of cap carbonates, the evidence for long-lived glaciers at sea level in the tropics, and the associated iron deposits. The strength of the hypothesis is that it simultaneously explains all these salient features, none of which had satisfactory independent explanations. What is more, we believe this hypothesis sheds light on the early evolution of animal life.

Survival and Redemption of Life

In the 1960s Martin J. S. Rudwick, working with Brian Harland, proposed that the climate recovery following a huge Neoproterozoic glaciation paved the way for the explosive radiation of multicellular animal life soon thereafter. Eukaryotes—cells that have a membrane-bound nucleus and from which all plants and animals descended—had emerged more than one billion years earlier, but the most complex organisms that had evolved when the first Neoproterozoic glaciation hit were filamentous algae and unicellular protozoa. It has always been a mystery why it took so long for these primitive organisms to diversify into the 11 animal body plans that show up suddenly in the fossil record during the Cambrian explosion [*see illustration on this page*].

A series of global freeze-fry events would have imposed an environmental filter on the evolution of life. All extant eukaryotes would thus stem from the survivors of the Neoproterozoic calamity. Some measure of the extent of eukaryotic extinctions may be evident in universal "trees of life." Phylogenetic trees indicate how various groups of organisms evolved from one another, based on their degrees of similarity. These days biologists commonly draw these trees by looking at the sequences of nucleic acids in living organisms.

Most such trees depict the eukaryotes' phylogeny as a delayed radiation crowning a long, unbranched stem. The lack of early branching could mean that most eukaryotic lineages were "pruned" during the snowball earth episodes. The creatures that survived the glacial episodes may have taken refuge at hot springs both on the seafloor and near the surface of the ice where photosynthesis could be maintained.

The steep and variable temperature and chemical gradients endemic to ephemeral hot springs would preselect for survival in the hellish aftermath to come. In the face of varying environmental stress, many organisms respond with wholesale genetic alterations. Severe stress encourages a great degree of

genetic change in a short time, because organisms that can most quickly alter their genes will have the most opportunities to acquire traits that will help them adapt and proliferate.

Hot-spring communities widely separated geographically on the icy surface of the globe would accumulate genetic diversity over millions of years. When two groups that start off the same are isolated from each other long enough under different conditions, chances are that at some point the extent of genetic mutation will produce a new species. Repopulations occurring after each glaciation would come about under unusual and rapidly changing selective pressures quite different from those preceding the glaciation; such conditions would also favor the emergence of new lifeforms.

Martin Rudwick may not have gone far enough with his inference that climatic amelioration following the great Neoproterozoic ice age paved the way for early animal evolution. The extreme climatic events themselves may have played an active role in spawning multicellular animal life.

We have shown how the worldwide glacial deposits and carbonate rocks in the Neoproterozoic record point to an extraordinary type of climatic event, a snowball earth followed by a briefer but equally noxious greenhouse world. But what caused these calamities in the first place, and why has the world been spared such events in more recent history? The first possibility to consider is that the Neoproterozoic sun was weaker by approximately 6 percent, making the earth more susceptible to a global freeze. The slow warming of our sun as it ages might explain why no snowball event has occurred since that time. But convincing geologic evidence suggests that no such glaciations occurred in the billion or so years before the Neoproterozoic, when the sun was even cooler.

The unusual configuration of continents near the equator during Neoproterozoic times may better explain how snowball events get rolling [*see illustration on page 52*]. When the continents are nearer the poles, as they are today, carbon dioxide in the atmosphere remains in high enough concentrations to keep the planet warm. When global temperatures drop enough that glaciers cover the high-latitude continents, as they do in Antarctica and Greenland, the ice sheets prevent chemical erosion of the rocks beneath the ice. With the carbon burial process stifled, the carbon dioxide in the atmosphere stabilizes at a level high enough to fend off the advancing ice sheets. If all the continents cluster in the tropics, on the other hand, they would remain ice-free even as the earth grew colder and approached the critical threshold for a runaway freeze. The carbon dioxide "safety switch" would fail because carbon burial continues unchecked.

Some say the world will end in fire,
Some say in ice.
From what I've tasted of desire
I hold with those who favor fire.
But if it had to perish twice,
I think I know enough of hate
To say that for destruction ice
Is also great
And would suffice.

—Robert Frost,
Fire and Ice (1923)

We may never know the true trigger for a snowball earth, as we have but simple theories for the ultimate forcing of climate change, even in recent times. But we should be wary of the planet's capacity for extreme change. For the past million years, the earth has been in its coldest state since animals first appeared, but even the greatest advance of glaciers 20,000 years ago was far from the critical threshold needed to plunge the earth into a snowball state. Certainly during the next several hundred years, we will be more concerned with humanity's effects on climate as the earth heats up in response to carbon dioxide emissions [see "The Human Impact on Climate Change," by Thomas R. Karl and Kevin E. Trenberth; SCIENTIFIC AMERICAN, December 1999]. But could a frozen world be in our more distant future?

We are still some 80,000 years from the peak of the next ice age, so our first chance for an answer is far in the future. It is difficult to say where the earth's climate will drift over millions of years. If the trend of the past million years continues and if the polar continental safety switch were to fail, we may once again experience a global ice catastrophe that would inevitably jolt life in some new direction. SA

The Authors

PAUL F. HOFFMAN and DANIEL P. SCHRAG, both at Harvard University, bring complementary expertise to bear on the snowball earth hypothesis. Hoffman is a field geologist who has long studied ancient rocks to unravel the earth's early history. He led the series of expeditions to northwestern Namibia that turned up evidence for Neoproterozoic snowball earth events. Schrag is a geochemical oceanographer who uses the chemical and isotopic variations of coral reefs, deep-sea sediments and carbonate rocks to study climate on timescales ranging from months to millions of years. Together they were able to interpret the geologic and geochemical evidence from Namibia and to explore the implications of a snowball earth and its aftermath.

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NAR

Although people with the movies, narcolepsy

After hearing the punch line of the joke, the teenager falls to the floor, almost as if actually punched. She remains there, completely unable to move. She hears her parents reassure her friends that they need not worry about her because she will be all right in a few minutes. She is embarrassed and frustrated as the episode continues, and her friends begin to leave. They bid her goodbye, but she is unable to respond. Although she cannot talk or move, she is otherwise in a state of high alertness, feeling, hearing and remembering everything that is going on around her. The episode lasts for five minutes, longer than her typical cataplexies—which often last only seconds—but shorter than her longest episode, which lasted 25 minutes. Then it ends, almost as abruptly as it began. She gets up from the floor, and her everyday life resumes.

DOG AND MAN with narcolepsy experience an attack of cataplexy—the complete loss of muscle tone while awake and conscious—in a similar fashion. In both, the attack causes the head to droop and the back and legs to sag; it can progress to a complete loss of muscle tone. Cataplexy is distinct from the sleep attacks that afflict most narcoleptics: people hear and remember what is said around them, and dogs can track a moving object with their eyes.

JAMES ARONOVSKY *(dog sequence)*; JOEL DEUTSCH *(human sequence)*; SLIM FILMS

COLEPSY

the disorder do not fall face-first into their soup as in is still a mysterious disease. But science has new leads

by Jerome M. Siegel

Cataplexy, the loss of skeletal muscle tone without loss of consciousness, is one of the defining symptoms of a puzzling neurological disorder called narcolepsy. The cataplectic attacks of narcolepsy are frequently prompted by laughter; other times, embarrassment, social interactions with strangers, sudden anger, athletic exertion or sexual intercourse may trigger an episode.

Another characteristic symptom of narcolepsy—and usually the most incapacitating one—is persistent daytime sleepiness. If you have ever gone without sleep for 48 hours, you have experienced the sleepiness that a narcoleptic lives with every day. In spite of being so sleepy, they tend to sleep poorly at night. And although they feel refreshed after a short nap, the sleepiness soon returns. As a result, narcoleptics fall asleep at dangerous or inappropriate times, as illustrated by the cartoon on the next page. Untreated, they are therefore at high risk for motor vehicle accidents and often have trouble reaching their potential in school and the workplace.

Within the past several years, researchers have begun to unravel the mysteries of this debilitating—but surprisingly common—disease. My colleagues and I have identified the specific regions of the brain that appear to be affected in cataplexy and have discovered that they are the same regions that normally prevent us from moving in synchrony with our dreams (for example, thrashing our legs when we dream we are in a race). We have also found the first evidence of neuronal degeneration in narcolepsy. Other scientists have isolated a gene that when mutated can cause narcolepsy in dogs. Perhaps most intriguingly, there are hints that narcolepsy might be an autoimmune disease, in which the immune system attacks normal brain tissue as foreign.

This disorder has a number of extraordinary features. Besides cataplexy and sleepiness, two other classic symptoms are sleep paralysis and so-called hypnagogic hallucinations. Sleep paralysis is an inability to move when falling asleep or awakening. Although normal individuals may have short periods of sleep paralysis a few times in their lives, it is a daily occurrence for many narcoleptics. Hypnagogic hallucinations are dreamlike experiences during waking that often incorporate elements of the environment. They usually occur when narcoleptics are most sleepy. Not every patient suffers in exactly the same way, however. For instance, the severity of cataplexy and sleepiness varies among individuals.

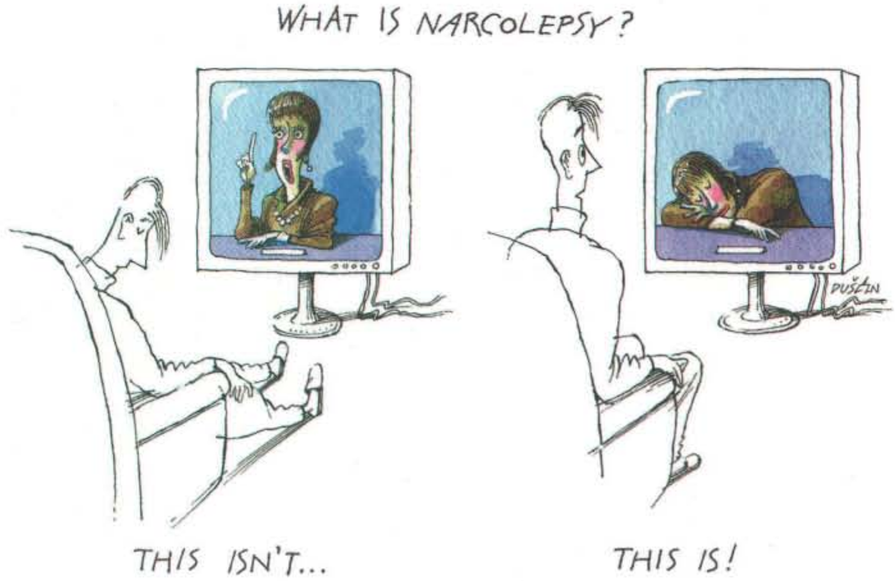
Narcolepsy is also surprising in its wide range of incidence. It affects between one in 1,000 and one in 2,000 people in the U.S. Rates in other countries range from one in 600 in Japan to one in 500,000 in Israel. Genetic factors linked to ethnicity or possibly environmental conditions may be responsible for this variation. The overall incidence of narcolepsy in the U.S. is about 10 times that of amyotrophic lateral sclerosis (Lou Gehrig's disease), half that of multiple sclerosis, five times that of cystic fibrosis and about one quarter that of Parkinson's disease. The first signs of narcolepsy typically begin in the teens or 20s. Symptoms worsen for a few years and then plateau.

Sleep and Narcolepsy

Narcolepsy is linked to a disruption of the sleep control mechanism. The sleep cycle normally consists of two primary phases: so-called rapid eye movement (REM) sleep and non-REM sleep.

Non-REM sleep is a quiet sleep state. The muscles are relaxed but maintain some tone, breathing is regular, the cerebral cortex generates high-voltage waves, and consumption of energy by the brain is minimal. Although REM sleep shares the loss of consciousness of the environment seen in non-REM sleep, it is physiologically quite different. Breathing and heart rate are irregular; characteristic rapid eye movements occur; the cortex generates fast, irregular, low-voltage waves similar to those present in alert waking; vivid dreams take place; and brain metabolism often exceeds levels seen when the subject is awake. Tone in the postural muscles, such as those in the back and legs, is absent during REM sleep, although twitches occasionally break through the motor quiescence.

People who are not narcoleptic begin their nighttime rest with non-REM sleep, with REM sleep following roughly 90 minutes later. But narcoleptics frequently go straight into REM sleep. Because of this trait—and because nar-



DUSAN PETRICIC, AFTER A CARTOON FROM THE AMERICAN NARCOLEPSY ASSOCIATION

coleptics experience loss of muscle tone and dreamlike hallucinations that normally occur only during REM sleep—researchers have hypothesized that these symptoms of narcolepsy result from the inappropriate triggering of some aspects of REM sleep.

Although sleep problems are the most common symptoms of narcolepsy, much of the basic research on the disease has used cataplexy as a starting point. Sleepiness is a normal phenomenon; it is the amount of sleepiness that is abnormal in narcolepsy. Therefore, it is difficult to know if particular episodes of sleepiness seen in narcoleptics are abnormal. Cataplexy, however, never occurs in normal individuals. It is easily quantified and has an abrupt onset that allows scientists to determine the time course of the neural events that trigger it. By observing and manipulating cataplexy, we hope to gain a clear insight into the pathology of narcolepsy.

Narcoleptic Dogs

A major advance in narcolepsy research occurred in the early 1970s, when investigators observed that some dogs display symptoms very similar to those of human narcoleptics. William C. Dement of Stanford University was given a litter of Doberman pinschers (and later a litter of Labrador retrievers), all of which were narcoleptic. The disease was transmitted as a recessive trait, which means that a particular dog developed the disease only if it inherited the trait from both its mother and its father. Accordingly, when Dement bred two narcoleptic dogs, all the offspring were narcoleptic. The dogs experienced cataplexy during vigorous play or when they were excited by being offered their favorite foods.

My colleagues and I have conducted electrophysiological studies on such dogs to try to elucidate the causes of the strange symptoms of narcolepsy. We use tiny electrodes to record the electrical impulses from nerve cells, or neurons, in the brain stem as they communicate with cells in other areas of the brain and spinal cord.

We began our studies with recordings from the brain stem because of experiments conducted in the 1940s by Horace W. Magoun of Northwestern University. Magoun discovered that when he electrically stimulated the medial medulla (a part of the brain stem), muscle tone vanished, almost as if he had thrown a switch for preventing movement. At the time of this discovery, the polio epidemic was sweeping the U.S. Magoun hypothesized that damage to the medulla could be responsible for some of the increases in muscle tone seen in the acute phase of polio and could also be responsible for increased tone seen in other neurological diseases.

Magoun did not connect his observation to sleep, because his finding was made before the 1953 discovery of REM sleep and the subsequent discovery of its associated muscle paralysis. Studies in animals now suggest that although the main function of the muscle-tone control system in the medulla is in suppressing muscle activity in REM sleep, it also has a role in regulating the general level of muscle tone in waking. This region is inactive when animals are moving, moderately active when animals sit or lie down, further activated during non-REM sleep and maximally active in REM sleep. When you try to relax or "turn off" your muscles, you are actually trying to "turn on" this brain region.

Based on Magoun's findings, we wondered whether unusual activity in the medial medulla might be responsible for the cataplectic episodes experienced by narcoleptics. In 1991 we found that this was indeed the case: neurons in this region fired when narcoleptic dogs had a cataplectic attack. What is more, we observed that in normal animals, cells in this part of the medial medulla fired at high rates only when the animals were in REM sleep. Our discovery made sense because we knew from other studies that REM sleep is the only time when normal individuals lose all muscle tone.

Extending this line of research, Elizabeth Schenkel in my laboratory demonstrated that otherwise normal animals whose medial medullas were damaged moved around during REM sleep, instead of being completely relaxed. Other studies by Michel Jouvet of Claude Bernard University in Lyon, France, and Adrian R. Morrison of the University of Pennsylvania had shown that damage to higher levels of the brain stem that connect with the medulla produced animals that raised their heads, walked and appeared to attack imaginary adversaries during REM sleep. For some reason, in narcolepsy a group of neurons that is supposed to be active only during REM sleep to suppress muscle tone and protect us from the elaborate motor programs that accompany our dreams is being triggered during waking [*see box on opposite page*].

Another series of studies carried out in my laboratory by Frank Wu indicates that a second group of nerve cells in an area of the brain stem called the locus coeruleus also plays a role in REM sleep and narcolepsy. These cells release norepinephrine, a molecule called a neurotransmitter that neurons use to communicate with one another. When norepinephrine is secreted into the bloodstream, it participates in the body's "fight-or-flight" response during emergencies. Norepinephrine-producing neurons in the locus coeruleus have been shown in normal animals to be active throughout waking but to be inactive when the animals are in REM sleep. Our experiments in narcoleptic dogs indicate that cells in the locus coeruleus become completely inactive

before and during cataplexy, just as they do during REM sleep.

The cessation of activity in norepinephrine-containing cells removes a source of excitation from motor neurons just as the parallel system in the medulla responsible for inhibiting motor neurons becomes active. The loss of excitation and concurrent increase of inhibition together are responsible for greatly reducing the activity and excitability of motor neurons. When motor neurons cease discharging, the muscles that they control relax. In REM sleep the reduction of motor neuron excitability prevents them from responding to the motor signals that accompany dreams. In cataplexy the same reduction in excitability prevents the motor neurons from responding to a narcoleptic's attempts to move.

Recording the activity of neurons in narcoleptic dogs has given us an insight into how cataplexy is triggered. But why do these inhibitory events occur during waking in narcoleptics? Why are they not confined to REM sleep, as in healthy individuals?

There are no clear answers to these questions, but two genetic studies have recently yielded clues that might help solve the mystery. Emmanuel Mignot of Stanford and his co-workers have identified the gene responsible for narcolepsy in dogs. His research group has determined that the dogs carry a mutation in the receptor for a neurotransmit-

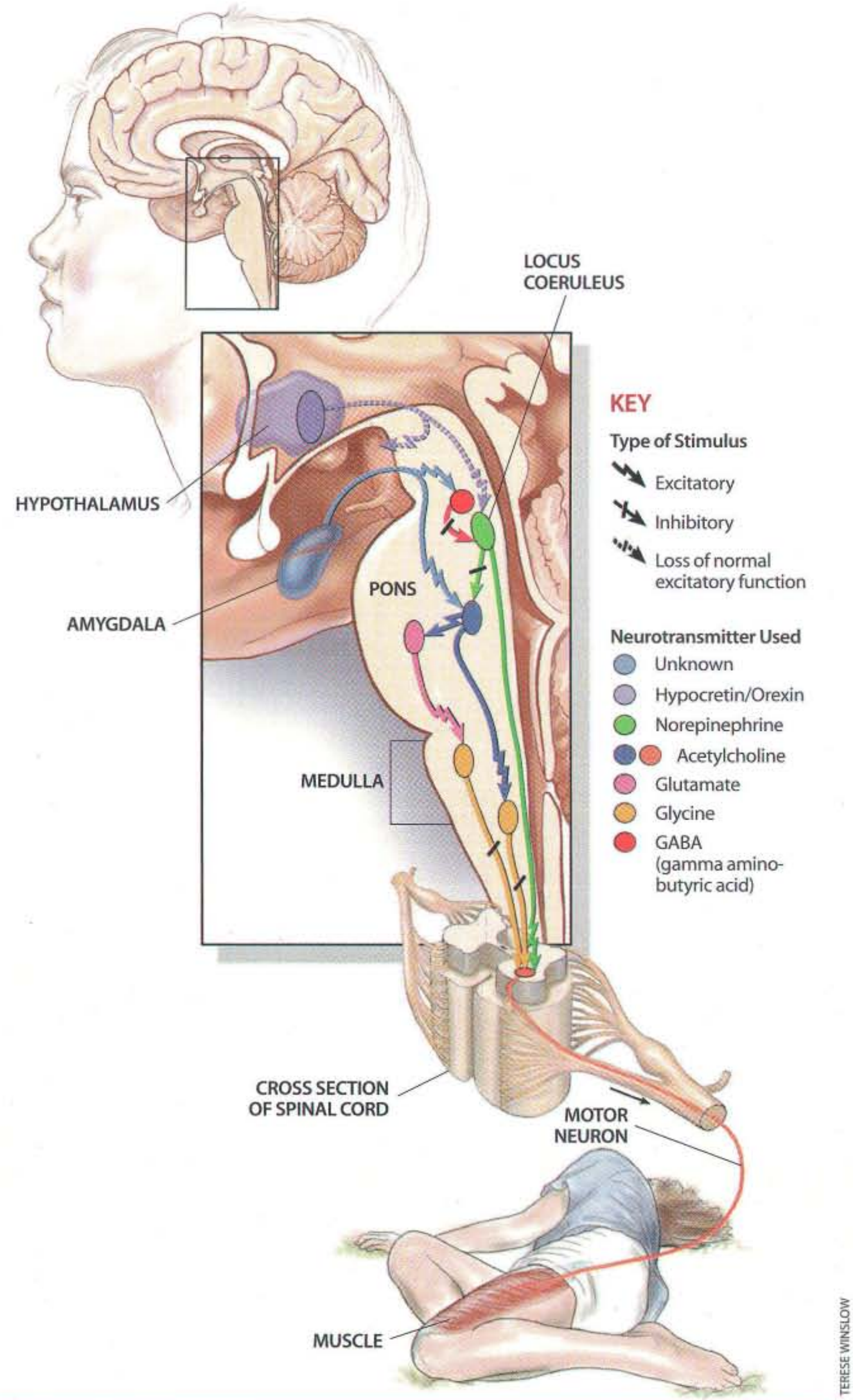
The Neural Circuitry of Narcolepsy

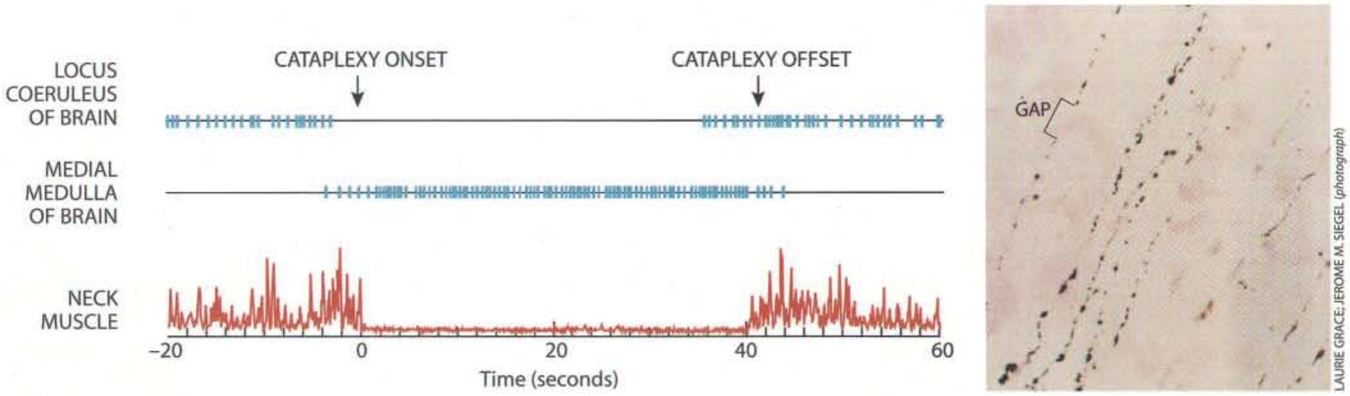
Brain and spinal cord circuits that normally inhibit movement during sleep are triggered inappropriately during cataplexy attacks in narcolepsy, causing a loss of tone in the muscles that maintain posture. The figure illustrates one simplified model of how this might occur.

The degeneration of cells in the forebrain eliminates inhibitory signals that are important for regulating the activity of cells in the amygdala, a structure involved in emotional responses. The loss of the inhibitory signals in the amygdala causes increased activity in amygdala connections (*light blue*) to the pons, in turn pressing a cellular "brake" (*red*) that reduces activity in the locus coeruleus (*green*). This removes a source of excitation from neurons (*orange*) that control muscles.

The cell loss in the amygdala also indirectly activates two circuits (*pink* and *dark blue*) in the pons that stimulate nerves in two areas of the medial medulla (*yellow*) that actively inhibit motor neurons. The result of the simultaneous loss of excitation and onset of inhibition in the motor neurons is a loss of muscle tone, causing the narcoleptic to fall.

Recent findings in narcoleptic dogs suggest that mutations in receptors for a neurotransmitter called hypocretin/orexin in the lateral hypothalamus can also cause cataplexy and the other symptoms of narcolepsy. The mutations may act by removing excitatory inputs (*violet*) to cells that maintain muscle tone and arousal and by triggering the degeneration seen in the forebrain. —*J.M.S.*





ELECTRICAL RECORDINGS (*left*) taken from the brain and neck muscles of a dog with narcolepsy show that cells in the locus coeruleus are inactive during the muscle paralysis of a cataplexy attack, whereas those in the medial medulla are active. The brain recordings (*blue*) were obtained using tiny electrodes; the muscle ones (*red*), with an electromyograph. The unusual activity patterns may result from the degeneration of cells in the amygdala: a slice from the amygdala of a dog (*right*) shows multiple gaps in the axons (*black streaks*) that normally extend from one nerve cell to another.

ter variously called hypocretin or orexin.

Neurotransmitter receptors sit on the surfaces of neurons like molecular locks. When a neurotransmitter "key" binds to its receptor, it sets off a chain reaction of chemical processes within the receiving cell that prompts the cell to take some action, such as sending its own neurotransmitter signal to a third cell. Mignot's group found that the mutation harbored by the narcoleptic dogs produces hypocretin/orexin receptors that are missing a critical part, so that they cannot respond normally to the messages they receive.

In a complementary study, researchers led by Masashi Yanagisawa of the Howard Hughes Medical Institute at the University of Texas Southwest Medical Center in Dallas have generated mice whose neurons cannot send the hypocretin/orexin message in the first place. They have observed that such mice also have some symptoms of narcolepsy, including REM sleep at sleep onset.

Hypocretin/orexin is made only in a region deep in the brain called the hypothalamus, which besides regulating body weight also controls water balance, pituitary functions, body temperature and many other processes. Hypocretin/orexin–producing neurons in the hypothalamus connect to other brain neurons that produce arousal, such as to the forebrain and brain-stem neurons that release acetylcholine and to other neurons that release histamine and serotonin. They are also linked up to brain-stem neurons, such as those in the locus coeruleus, that play an important role in the control of muscle tone.

Mutations that affect the hypocretin/orexin system might be responsible for some cases of narcolepsy in humans, but it is unlikely that most human narcoleptics have mutations in the genes responsible for synthesizing hypocretin/orexin or its receptor. Most narcoleptics have no narcoleptic relatives, and the disease does not arise until the second or third decade of life. In addition, in 75 percent of cases in which narcolepsy occurs in an identical twin, the other twin is unaffected. These findings indicate that environmental conditions are important in human narcolepsy. These environmental conditions may cause damage to the hypocretin/orexin system, mimicking the symptoms caused by mutations, or may prompt damage to closely linked systems of neurons.

An Autoimmune Disease?

Some scientists have proposed that narcolepsy arises when unknown agents in the environment spur an autoimmune reaction that winds up damaging neurons in the brain circuits that control arousal and muscle tone. In 1984 Yutaka Honda and his colleagues at Seiwa Hospital in Tokyo found that all members of a group of 135 Japanese narcoleptics had one aspect of their tissue type in common, which meant their immune systems used the same molecule, one of the human leukocyte antigens (HLAs), to tell friend from foe. The molecule the narcoleptics shared was found in approximately 35 percent of nonnarcoleptic Japanese. Whereas the HLA type was clearly not sufficient to induce narcolepsy, Honda's finding indicated that HLA type greatly affected susceptibility to the disease.

HLA molecules are pitchfork-shaped structures that cells of the body use to show pieces of the proteins they contain to the immune system. Cells of the immune system ordinarily attack foreign substances and cells infected by viruses, which hijack cells into making viral proteins instead of normal ones.

Someone's HLA type is often referred to as their tissue type because people with the same HLA profile can receive tissue or organ transplants from one another. Certain autoimmune diseases tend to afflict those with particular HLA types, most likely because those HLA types when linked to particular antigens may look like naturally occurring proteins in the body, thereby causing the immune system to become confused and to damage normal cells.

The obvious next step will be to determine whether the immune systems of narcoleptics are mistakenly targeting the hypocretin/orexin receptors in their own brains as foreign. Because the body would continue to regenerate the receptors, such an autoimmune response would be expected to continue for the duration of the disease, but no such response has yet been detected in people with narcolepsy.

In another scenario the autoimmune response might be destroying the neurons or the parts of neurons that bear the hypocretin/orexin receptors, so that the autoimmune response would cease. Alternatively, the deficit in human narcolepsy could occur farther along the neuronal circuits regulating sleep than those cells involved in the hypocretin/orexin system. Autoimmune damage to neurons or receptors in the locus coeruleus or in other sleep-related regions of the brain might produce the syndrome even though the

hypocretin/orexin neurons and their receptors were functioning normally.

Evidence for an autoimmune cause of narcolepsy will most likely come from studies of the brains of people who had the disorder. Ever since French physician Jean Baptiste Edouard Gélineau named narcolepsy as a distinct syndrome in 1880, researchers have examined the brains of patients in a futile search for neurological damage that could explain the symptoms of the disease. In a series of studies in the 1980s and 1990s, Mignot, Dement and their Stanford colleagues Ted L. Baker and Thomas S. Kilduff observed that the brains of narcoleptic dogs had more than the usual number of receptors for the neurotransmitters acetylcholine, dopamine and norepinephrine and higher levels of some of the neurotransmitters themselves.

In the early 1990s Michael S. Aldrich of the University of Michigan noted similar changes in the brains of human narcoleptics. Such alterations in neurotransmitter and receptor levels, however, can result from behavioral changes—including sleep disturbances—so it has been unclear if they are the cause or the result of the disease.

My colleagues and I considered this issue and wondered whether pathologists had failed to find consistent evidence for brain damage in narcoleptics because they had been looking at the wrong time in the disease process. Narcolepsy is a chronic disease but not a progressive one. After symptoms are fully established, narcoleptics do not get progressively worse or markedly better. This suggests that the damage might occur during a short time, roughly during the period in which a patient first develops signs of the illness. Debris left over from degenerative processes that occurred at the age of 20 would be removed by the brain's support cells long before most patients died, and any remaining clues would be obscured by the normal degeneration of aging. A loss of neurons would be undetectable unless the dead cells were concentrated in a particular area, as in Parkinson's disease, or unless many, many neurons died, as in Alzheimer's disease.

Accordingly, my co-workers and I examined the brains of narcoleptic dogs shortly after their symptoms had begun. Using a stain that detects damaged neurons, we found clear evidence that neurons in certain areas of the dogs' brains were degenerating between one and two months of age—just before and during the onset of symptoms. Evidence of the degeneration largely disappeared by the time the dogs were six months old.

The degeneration in the dogs was most pronounced in the amygdala, a brain structure known to be involved in emotion and in inducing sleep, and adjacent regions at the bottom of the forebrain. Remarkably, although the brain stem mediates some of the symptoms of narcolepsy, it showed no clear signs of degeneration. We hypothesize that damage to the amygdala and adjacent forebrain areas can cause the motor symptoms of narcolepsy by inappropriately activating brain-stem circuits that are undamaged, just as a properly functioning car can run out of control if the person inside steps on the accelerator at the wrong time.

We have found the first evidence of neuronal degeneration in narcolepsy.

As usual in science, our findings answered one question but generated even more. What causes the damage we observed in the amygdala and other forebrain regions in the young dogs? Is it the result of an autoimmune process, as suggested by the human study? Does the abnormality in the hypocretin/orexin receptor trigger the damage? Is it possible to prevent or even reverse the damage?

Until we can find answers, all we can offer people with narcolepsy are drugs to control their symptoms. We can counteract some of the sleepiness experienced by narcoleptics using stimulants such as Ritalin and Cylert or amphetamines, which activate dopamine receptors to increase the overall level of arousal. Another drug, Provigil, whose mechanism of action is not clear, may act by stimulating hypocretin/orexin neurons and other neural populations in the hypothalamus that in turn activate brain arousal systems. The downside is that such drugs are effective only for short periods and can cause unpleasant side effects, such as agitation, dry mouth and anxiety.

To prevent the cataplectic attacks of narcolepsy, physicians can prescribe agents that increase the availability of norepinephrine in the brain. These include monoamine oxidase inhibitors—which block the enzyme that destroys norepinephrine after it is released by neurons—and drugs such as Prozac, whose breakdown products activate norepinephrine receptors. Gamma hydroxybutyrate (GHB), whose mode of action is unclear, can also be effective against cataplexy.

Our newfound understanding of the processes underlying narcolepsy gives us reason to hope that new treatments that restore the imbalance in the hypocretin/orexin, norepinephrine and other neurotransmitter systems that control the sleep-wake cycle will improve treatment of this disease. We are entering a promising era in narcolepsy research. SA

The Author

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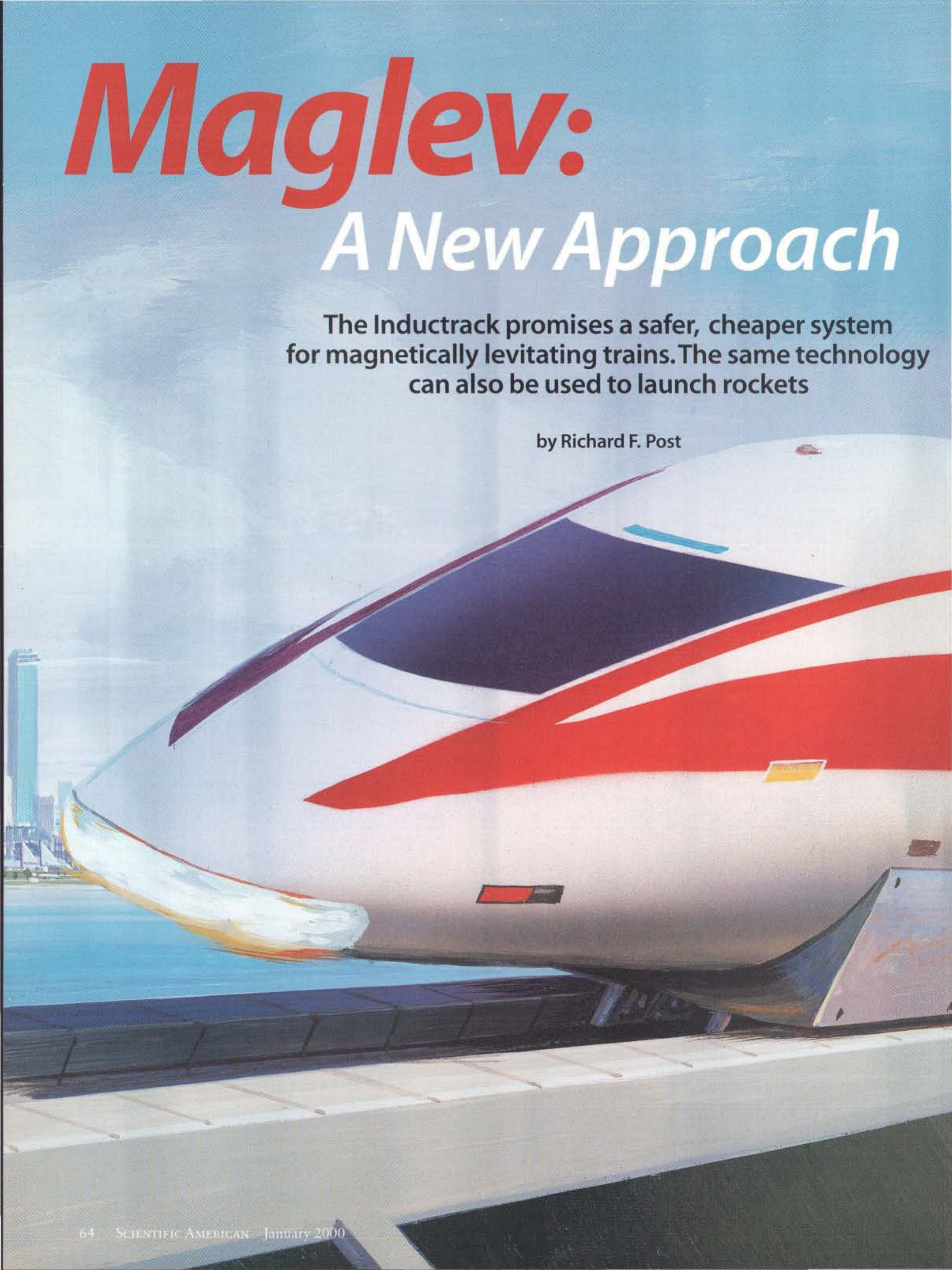
Links to additional articles can be found at www.bol.ucla.edu/~jsiegel on the World Wide Web.

Maglev: A New Approach

The Inductrack promises a safer, cheaper system for magnetically levitating trains. The same technology can also be used to launch rockets

by Richard F. Post



The story "Prince Ahmed and the Fairy," one of the classic tales in *The Thousand and One Nights,* tells of a prince who flew from place to place on a magic carpet, supported by invisible forces. The modern version of the magic carpet is the magnetically levitated train, or maglev, which can travel faster and more efficiently than ordinary trains because it rides on air instead of steel rails. The concept took off in the late 1960s, when Gordon T. Danby and James R. Powell of Brookhaven National Laboratory proposed using superconducting coils to produce the magnetic fields that would levitate the trains. In the 1970s and 1980s demonstration maglevs were built in Germany and Japan. Yet despite the appeal of the technology, which promises smooth-as-silk train rides at speeds up to 500 kilometers per hour, no full-scale commercially operating maglev system has been constructed.

Why is this so? For one, the maglevs that have been demonstrated so far are much more expensive and complex than conventional railways. The Japanese system, for example, requires costly cryogenic equipment on the train cars to cool the superconducting coils, which must be kept below about five kelvins to operate efficiently. The German maglev uses conventional electromagnets rather than superconducting ones, but the system is inherently unstable because it is based on magnetic attraction rather than repulsion. Each train car must be equipped with sensors and feedback circuits to maintain the separation between the car's electromagnets and the track. What is more, neither system is fail-safe. A breakdown of the magnet control circuits or power systems could lead to a sudden loss of levitation while the train is moving. Careful design can minimize the hazards of such a failure but not without a further increase in cost and complexity.

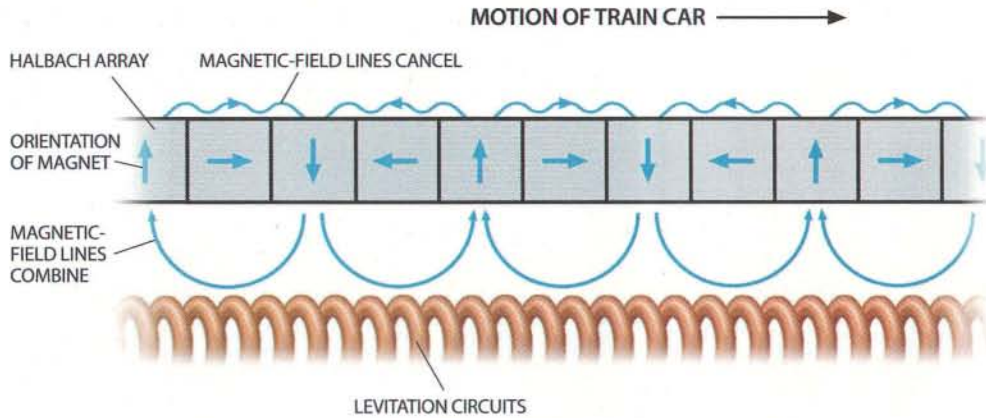
All Aboard the Inductrack

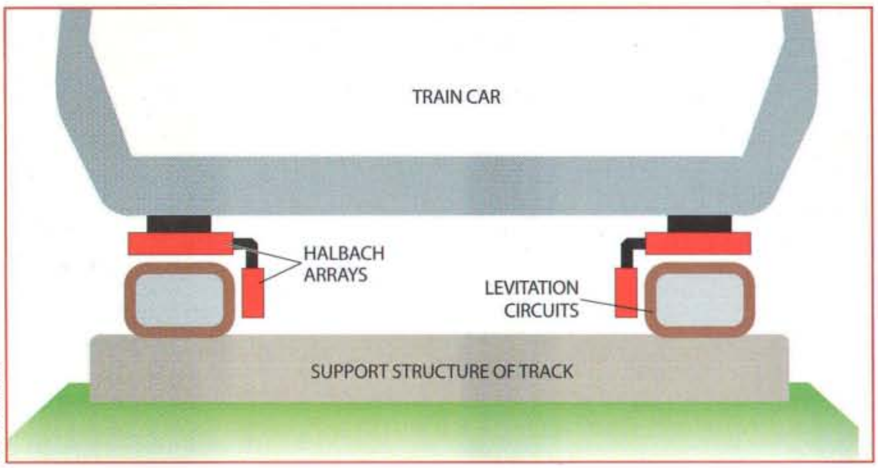
At Lawrence Livermore National Laboratory, we are exploring a different approach to magnetic levitation, one that could be simpler and less expensive to implement. The idea arose from earlier research on an electromechanical battery for cars and trucks. Such a battery stores kinetic energy using a flywheel, which requires nearly frictionless magnetic bearings to minimize energy loss. The bearings developed at Livermore employed cylindrical magnet arrays to sta-

INDUCTRACK MAGLEV SYSTEM could allow trains to glide across the country at up to 500 kilometers per hour. The new technology would employ arrays of permanent magnets on the undersides of the train cars, which would levitate a few centimeters above the tracks. Such a system is projected to be cheaper and safer than maglevs using electromagnets or superconducting coils.

ATTILA HEJJA

PERMANENT MAGNETS under an Inductrack train car are arranged in a Halbach array (*right*) so that the magnetic-field lines reinforce one another below the array but cancel one another out above it. When moving, the magnets induce currents in the track's circuits, which produce an electromagnetic field that repels the array, thus levitating the train car. Halbach arrays can also provide lateral stability if they are deployed alongside the track's circuits (*below*).





GEORGE RETSECK

bilize the levitation of the flywheel. We soon realized that if we unrolled these stabilizers, we would have the basis for a new type of maglev.

Called the Inductrack, the new system is passive in that it uses no superconducting magnets or powered electromagnets. Instead it uses permanent room-temperature magnets, similar to the familiar bar magnet, only more powerful. On the underside of each train car is a flat, rectangular array of magnetic bars called a Halbach array. (It is named after its inventor, Klaus Halbach, a retired Lawrence Berkeley National Laboratory physicist.) The bars are arranged in a special pattern, so that the magnetic orientation of each bar is at right angles to the orientations of the adjacent bars [*see top illustration on this page*]. When the bars are placed in this configuration, the magnetic-field lines combine to produce a very strong field below the array. Above the array, the field lines cancel one another out.

The second critical element is the track, which is embedded with closely packed coils of insulated wire. Each coil is a closed circuit, resembling a rectangular window frame. The Inductrack, as its name suggests, produces levitating force by inducing electric currents in the track. Moving a permanent magnet near a loop of wire will cause a current to flow in the wire, as English physicist Michael Faraday discovered in 1831. When the Inductrack's train cars move forward, the magnets in the Halbach arrays induce currents in the track's coils, which in turn generate an electromagnetic field that repels the arrays. As long as the train is moving above a low critical speed of a few kilometers per hour—a bit faster than walking speed—the Halbach arrays will be levitated a few centimeters above the track's surface.

The magnetic field acts much like a compressed spring: the levitating force increases exponentially as the separation between the track and the train car decreases. This property makes the Inductrack inherently stable—it can easily adjust to an increasing load or to acceleration forces from rounding a bend in the track. Thus, the system would not require control circuits to maintain the levitation of the train cars. All the train would need is some source of drive power to accelerate it.

In the past, engineers believed permanent magnets could not be used in maglev systems, because they would yield too little levitating force relative to their weight. The Inductrack's combination of Halbach arrays and closely packed track coils, however, results in levitation forces approaching the theoretical maximum force per unit area that can be exerted by permanent magnets. Calculations show that by using high-field alloys—neodymium-iron-boron, for example—it is possible to achieve levitating forces on the order of 40 metric tons per square meter with magnet arrays that weigh as little as 800 kilograms per square meter, or one fiftieth of the weight levitated.

In a full-scale Inductrack system, the track would consist of two rows of tightly packed rectangular coils, each corresponding to one of the steel rails in a conventional track. The main levitating Halbach arrays would be placed on the underside of the train car so that they would run just above the rows of coils [*see bottom illustration on this page*]. Smaller Halbach arrays could be deployed alongside the rows of coils to provide lateral stability for the train car. Such a configuration would somewhat resemble its counterpart in an ordinary train—namely, a flanged wheel rolling on a steel rail. In the Inductrack the role of the "flanges" is played by the small side-mounted Halbach arrays, whereas the role of the "wheel" is fulfilled by the main levitating arrays.

The Issue of Efficiency

A primary concern for any maglev is the efficiency of the levitating system. Unlike the German and Japanese maglevs, the Inductrack requires no power to produce its magnetic field, because it uses permanent magnets. Therefore, this particular source of inefficiency is not an issue. To levitate the train car, though, currents must be induced in the track's circuits, and electrical resistance

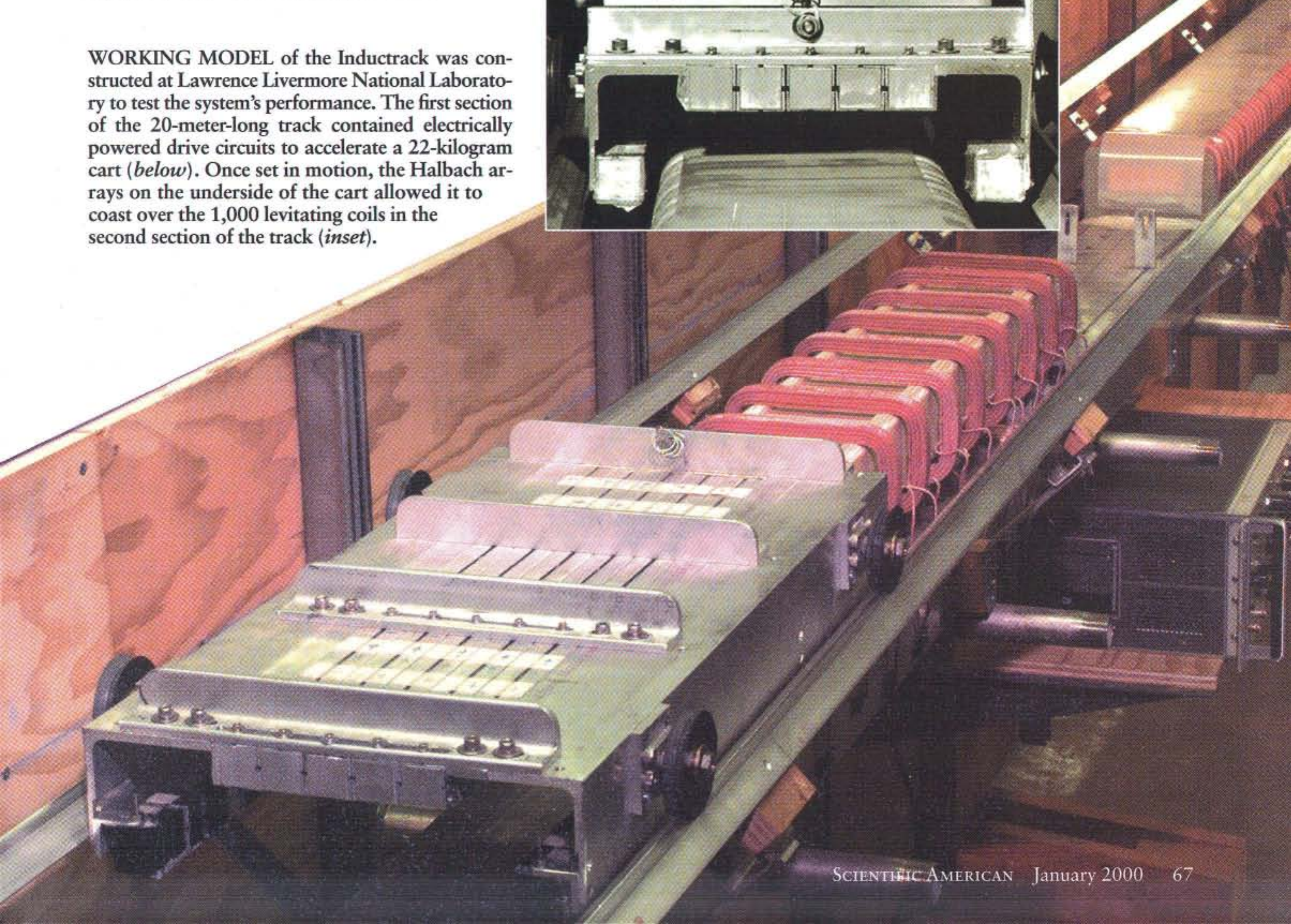
in the circuits will dissipate some of the power, converting it to heat. This power loss, coming as it does from the motion of the train relative to the track, will result in drag forces. These drag forces are the magnetic counterpart of the frictional drag associated with wheels and bearings in a conventional train. In the Inductrack, the magnetic drag forces vary inversely with the train's velocity, becoming very low at typical maglev speeds (250 to 500 kilometers per hour). These drag forces thus behave in an opposite way to wheel-frictional drag forces or aerodynamic drag, both of which increase with rising speed.

In aircraft, a common way to gauge the performance of an airfoil is to calculate its lift-to-drag (L/D) ratio—the ratio of its lifting power to its aerodynamic drag. At typical flying speeds, the L/D ratio of the wing of a jet aircraft is about 25 to 1 and does not vary much with velocity. In the Inductrack system the corresponding ratio relates magnetic lift—the levitating force—to magnetic drag. We were able to find a formula for the Inductrack's L/D ratio by performing a detailed theoretical analysis of the system. Much help came from my coworker at the Livermore laboratory, Dmitri D. Ryutov, formerly at the Budker Institute of Nuclear Physics in Novosibirsk, Russia. Ryutov is recognized internationally for his contributions to the theory of magnetically confined plasmas for fusion, and he applied techniques from that discipline to his analysis of the Inductrack.

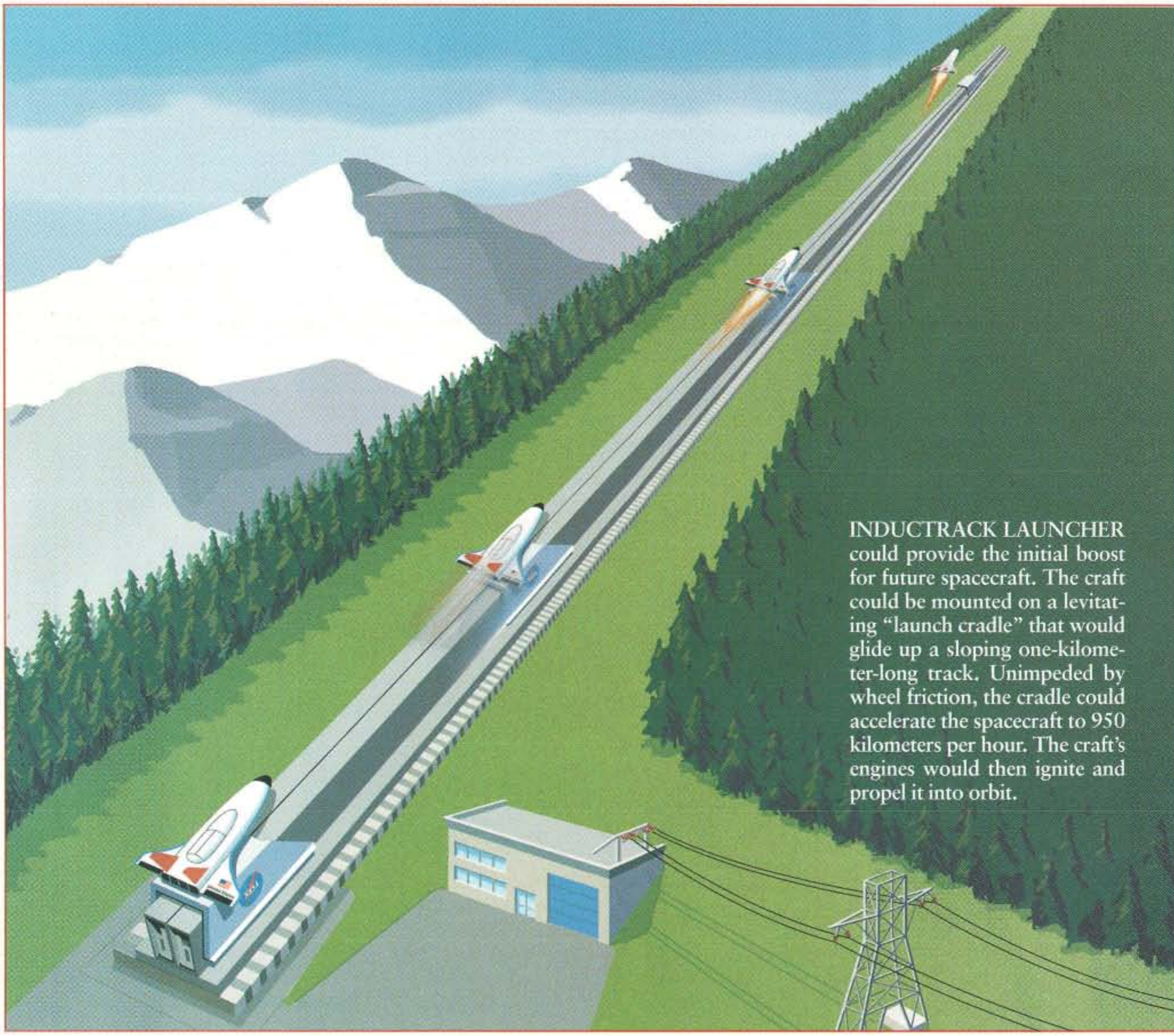
We found that the Inductrack's L/D ratio is directly proportional to the speed of the moving Halbach arrays. When the train is at rest, there is obviously no levitating force, and the L/D ratio is zero. But as the train begins to move, the levitating force rises quickly, reaching half its maximum value at a speed between two and five kilometers per hour. We call this the transition speed—at this velocity, the magnetic lift and drag are equal. At twice the transition speed, the levitating force reaches 80 percent of its maximum value and the L/D ratio rises to about five. Thus, we see that the Inductrack's levitation becomes effective when the train is moving very slowly. If the cars are equipped with auxiliary wheels, the train can run on rails until it reaches the transition speed, at which point it would begin levitating. Furthermore, the system's efficiency continues to improve as the train gathers speed—the L/D ratio can reach values as high as 200 to 1 at a velocity of 500 kilometers per hour. And if the drive power suddenly fails, the train cars would remain levitated while slowing down to a very low speed, at which point the cars would come to rest on their auxiliary wheels.

Another way to evaluate the efficiency of the Inductrack maglev system is to measure the power loss from magnetic drag and compare it with other power losses. With a 50,000-kilogram train car

LAWRENCE LIVERMORE NATIONAL LABORATORY



WORKING MODEL of the Inductrack was constructed at Lawrence Livermore National Laboratory to test the system's performance. The first section of the 20-meter-long track contained electrically powered drive circuits to accelerate a 22-kilogram cart (*below*). Once set in motion, the Halbach arrays on the underside of the cart allowed it to coast over the 1,000 levitating coils in the second section of the track (*inset*).



GEORGE RETSECK

INDUCTRACK LAUNCHER could provide the initial boost for future spacecraft. The craft could be mounted on a levitating "launch cradle" that would glide up a sloping one-kilometer-long track. Unimpeded by wheel friction, the cradle could accelerate the spacecraft to 950 kilometers per hour. The craft's engines would then ignite and propel it into orbit.

running at 500 kilometers per hour, about 300 to 600 kilowatts of power would be dissipated in the track's levitating circuits. In contrast, the aerodynamic drag on the train car at that speed would cause a power loss of nearly 10 megawatts. In other words, the power needed to keep the train car levitated is less than one tenth of that required to overcome wind resistance.

Drive Systems for the Inductrack

Thus far I have described only one type of Inductrack circuit—namely, a row of rectangular coils. The track, however, might take many other forms, depending on the performance that is desired. For example, the track could consist of stacks of thin sheets of aluminum, with insulating films placed between the layers. When the Halbach arrays move above these stacks, the magnetic fields would induce electric currents in the aluminum sheets. A series of parallel slots would be etched into each sheet to create the optimal path for the electrons, minimizing eddy currents that would increase power losses. Such a track would exert a greater levitating force than a row of rectangular coils would, and it might also be cheaper to manufacture.

Another alternative is to increase the track's efficiency through a method called inductive loading. It can be applied to the rectangular circuits by placing tiles of ferrite—a magnetic ceramic containing iron oxide—around the bottom section of each coil. This change would decrease the current induced in the coils by the Halbach arrays and hence cut the power loss caused by electrical resistance. Because the magnetic drag would be lower, the magnetic lift would overcome it more easily, and the train would begin levitating at a lower transition speed. Inductive loading involves a trade-off, though: it would reduce the system's maximum levitating force below the 40 metric tons per square meter that is possible with the simpler track construction.

One of the virtues of the Inductrack is that it could accommodate a wide variety of drive systems for the trains. If the track can be hooked up to a power grid, the train cars could be propelled by "drive coils" interspersed among the track's levitating circuits. Supplied with current from the grid, the drive coils would generate electromagnetic fields that would interact with the fields from the Halbach arrays. Pulsing the drive coils in synchronization with the train's motion will result in accelerating or decelerating forces on the train cars. In situations where electrification of the rail line could be too expensive—for example, in rural areas between distant cities—the maglev train could be equipped with a shrouded propeller driven by a gas

turbine. Because wind resistance would be the only significant drag force on the train, a single propeller would be sufficient to accelerate the maglev to high speeds.

After we completed our theoretical analysis of the Inductrack, our team proceeded to the next logical step: building a small working model of the system. Its purposes were to check the theory's predictions and to demonstrate stable levitation. The 20-meter-long test track was designed to levitate a 22-kilogram cart equipped with Halbach arrays on its underside. The first section of the track contained electrically powered drive circuits; the second section consisted of 1,000 thin, rectangular levitating coils, each about 15 centimeters wide.

At the start of each test run, the cart rolled on its auxiliary wheels over the drive circuits, which accelerated the vehicle to a speed of 12 meters per second. This was sufficient to allow the cart to levitate above the rectangular coils (the track's transition speed was only four meters per second). The cart coasted over nearly the whole length of the track before settling on its wheels at the far end. We measured the cart's velocity and oscillations using two pointer-type lasers that were mounted on the cart at a slight angle to each other, like a pair of crossed eyes. The lasers illuminated spots on a white screen at the end of the track; analysis of a video-camera record of the spot separations and locations yielded plots of the cart's position and its pitch-and-yaw motions.

The tests verified our predictions of the Inductrack's performance and proved that the concept is workable. What is more, a preliminary feasibility study conducted in 1997 by the consulting company of Booz-Allen & Hamilton concluded that a full-scale Inductrack system would be less expensive to build and operate than the German maglev. For example, the study estimated that a train car equipped with Halbach arrays would cost between \$3.2 million and \$4.2 million, whereas a car in the German maglev would cost more than \$6 million. (The estimated cost of a Japanese maglev car has not been made available.) The Inductrack vehicle would be more expensive than a conventional railcar, which costs between \$2 million and \$3 million, and building the system's track could cost as much as 80 percent more than constructing an ordinary track. The study noted, however, that the Inductrack's energy usage and maintenance costs would be significantly lower than those of a conventional railway.

Other Applications: Launching Rockets?

After the construction of the test track at Livermore, officials at the National Aeronautics and Space Administration became aware of our work. As a result, the space agency awarded the laboratory a contract to build another model, aimed at demonstrating a very different application of the Inductrack concept. Studies by NASA have shown that if their rockets could be accelerated up a sloping track to speeds on the order of Mach 0.8 (950 kilometers per hour) before the rocket engines were fired up, it could substantially cut the cost of launching satellites. Such a system could reduce the required rocket fuel by 30 to 40 percent, thereby making it easier for a single-stage vehicle to boost a payload into orbit. Our Inductrack model, which will have a track about 100 meters long, will be designed to accelerate a 10-kilogram "launch cradle"—the rocket's platform—to speeds of about Mach 0.5 (600 kilometers per hour). Because of the shortness of the test track (compared with the kilometer-or-so length of a full-scale system), the electrical drive circuits for the NASA model must achieve 10-g acceleration levels. In a full-scale system the acceleration levels, limited by the strength and weight of the rocket itself, would be more modest, on the order of 3 g's.

Another possible application of the Inductrack was conceived by California inventor and entrepreneur Douglas J. Malewicki. His proposed maglev system, known as SkyTran, would transport small, two-passenger cars at up to 160 kilometers per hour. The podlike cars would be suspended from a monorail-type track that would support the levitating circuits. The cars would be available, on call, at each station in the system. After the passengers board a car, it would glide up to the main track and merge with the traffic speeding by the station. As a car approached its destination, it would switch to an exit track, dropping down to the station to allow the passengers to disembark.

As with any new technology aimed at improving or supplanting an older one, only time will tell how the Inductrack will be employed. In making the transition from theory and models to a full-scale system, several technological issues will have to be addressed. For example, to make the Inductrack's ride more comfortable, the system must damp out motions caused by aerodynamic forces. Another challenge would be clearing the track of any metallic junk that might be attracted to the Halbach arrays. (To accomplish this, the train's lead car could conceivably be equipped with the magnetic equivalent of a cowcatcher.)

In addition, the Inductrack's designers face the economic challenge of keeping costs low enough to provide a compelling advantage over conventional railways. I believe, however, that the essential simplicity and flexibility of the concept will ensure that it finds many applications—not only for high-speed rail systems but also for uses that we have not even imagined.

The Author

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Further Information

More information on the Inductrack system is available at www.llnl.gov/str/Post.html on the World Wide Web.

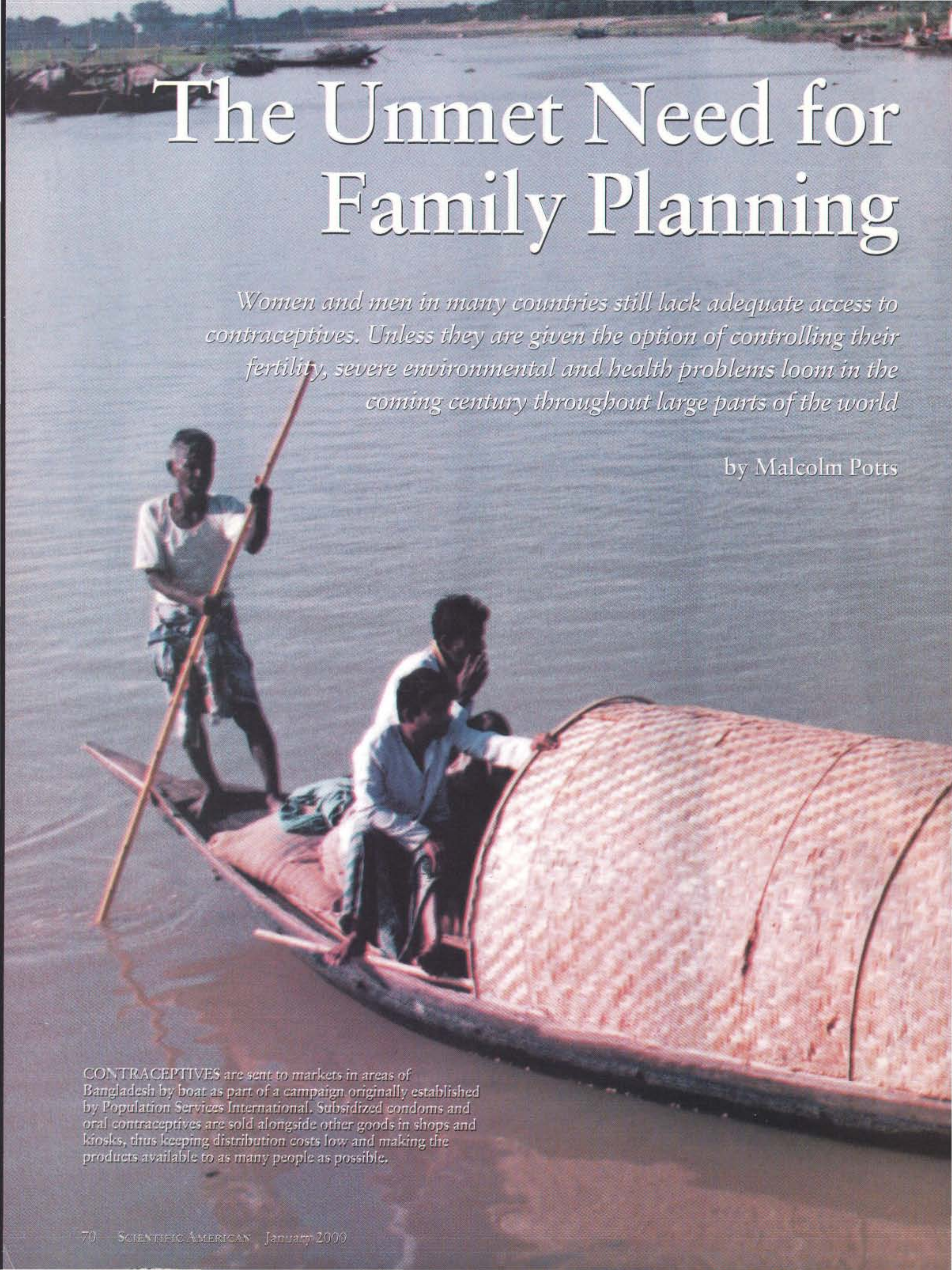
The home page of the Railway Technical Research Institute, developer of the Japanese maglev, is at www.rtri.or.jp/index.html on the World Wide Web.

The home page of the Transrapid System, the German maglev, is at www.maglev.com/english/index.htm on the World Wide Web.

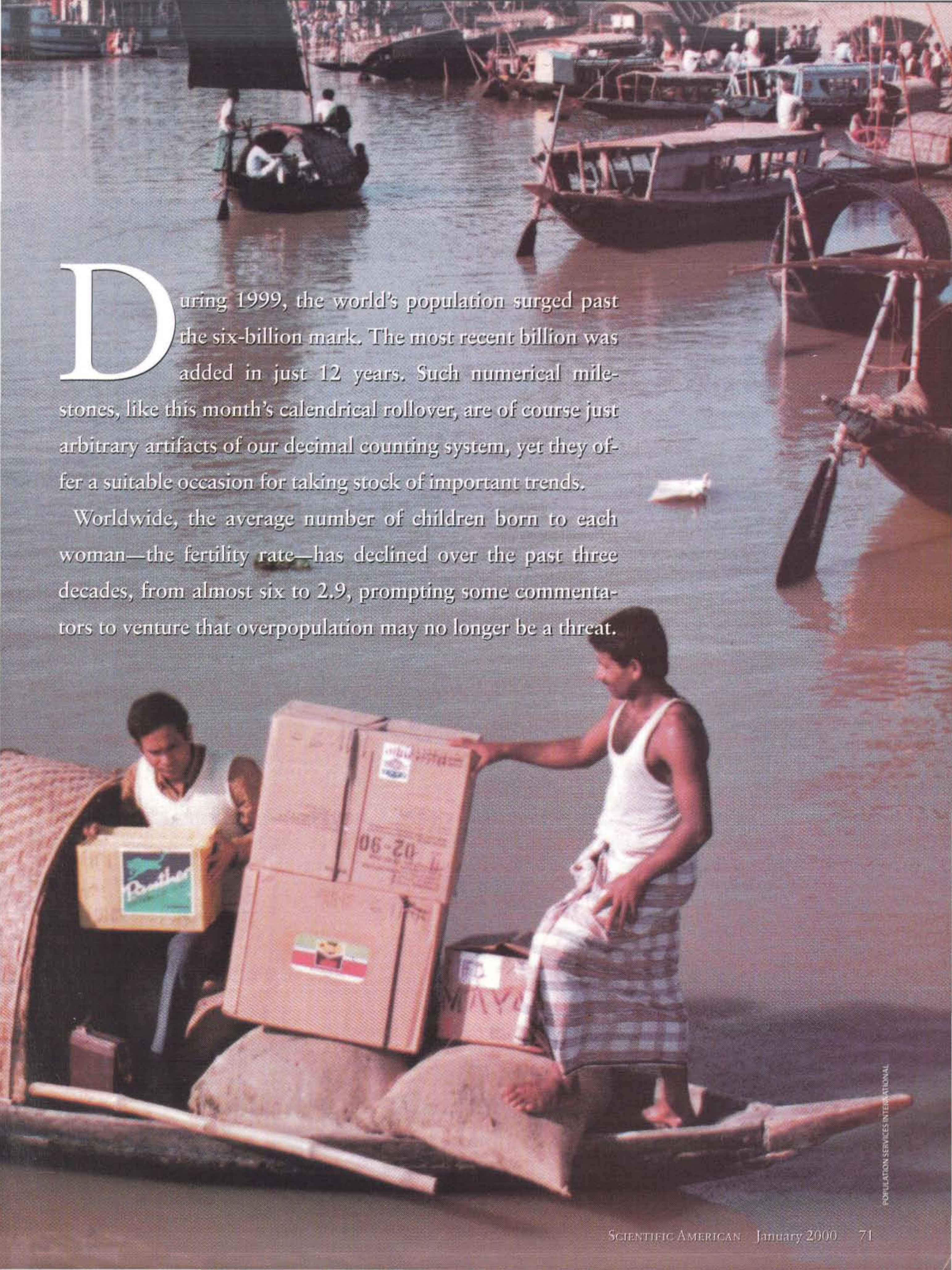
The Unmet Need for Family Planning

Women and men in many countries still lack adequate access to contraceptives. Unless they are given the option of controlling their fertility, severe environmental and health problems loom in the coming century throughout large parts of the world

by Malcolm Potts



CONTRACEPTIVES are sent to markets in areas of Bangladesh by boat as part of a campaign originally established by Population Services International. Subsidized condoms and oral contraceptives are sold alongside other goods in shops and kiosks, thus keeping distribution costs low and making the products available to as many people as possible.



POPULATION SERVICES INTERNATIONAL

During 1999, the world's population surged past the six-billion mark. The most recent billion was added in just 12 years. Such numerical milestones, like this month's calendrical rollover, are of course just arbitrary artifacts of our decimal counting system, yet they offer a suitable occasion for taking stock of important trends.

Worldwide, the average number of children born to each woman—the fertility rate—has declined over the past three decades, from almost six to 2.9, prompting some commentators to venture that overpopulation may no longer be a threat.

They are mistaken. Global population is still increasing by about 78 million people—a number equivalent to a new Germany—each year. Moreover, because large families were common in most of the world until recently, many countries have very large numbers of young people.

This population structure means that rapid growth is sure to continue for decades to come, almost all of it in developing countries, where family-planning services may be deficient or nonexistent. In nations that lack adequate medical, financial and educational institutions, not to mention food and water supplies, the result of a fast-growing population is much human misery. The quality of life of a large proportion of humanity during the coming century—and the future size of the global population—will depend critically on how quickly the world can satisfy the currently unmet demand for family planning.

Every day more than 400,000 conceptions take place around the world. Almost half are deliberate, happy decisions, but half are unintended, and many of these are bitterly regretted. A series of surveys in over 50 low-income countries has asked more than 300,000 women how many children they want to have. In nearly every country surveyed, women are bearing more offspring than they intend. When I practiced obstetrics in a London hospital in the 1960s, I would ask new mothers, "When do you want your next baby?" Many replied, "Doctor, I was just going to ask you about that." They were glad, in other words, that I had opened the door to an embarrassing but important topic. My boss in the hospital, however, berated me for discussing birth control. I learned that family planning was wanted but controversial.

During the past 30 years, many countries have greatly improved their provision of family-planning services. Contraceptive use in the developing world has risen from one in 10 couples to more than half of all couples. A 15 percent increase in the use of contraceptives means, on average, about one fewer birth per woman. Thus, in Ethiopia only 4 percent of women use contraception and the fertility rate is seven, while in South Africa 53 percent use some method and average fertility is 3.3. The desire for smaller families is spreading. In 1998 researchers associated with the Asian Development Bank in Laos, one of the world's poorest countries, invited people there to say what help they wanted most. The men requested jobs, but the women's number-one priority was family planning.

The unmet need for contraceptives is clearly on a different scale in Ethiopia or West Africa, where women commonly bear six children, than in, say, Italy, which has one of the lowest fertility rates in the world—1.2. Yet wherever people have said they want fewer children and family planning has been made available, fertility has fallen. What they need is access to a variety of methods, backed up by safe abortion if they choose it. The pill, the condom and injectables are the types most likely to be widely useful in developing countries.

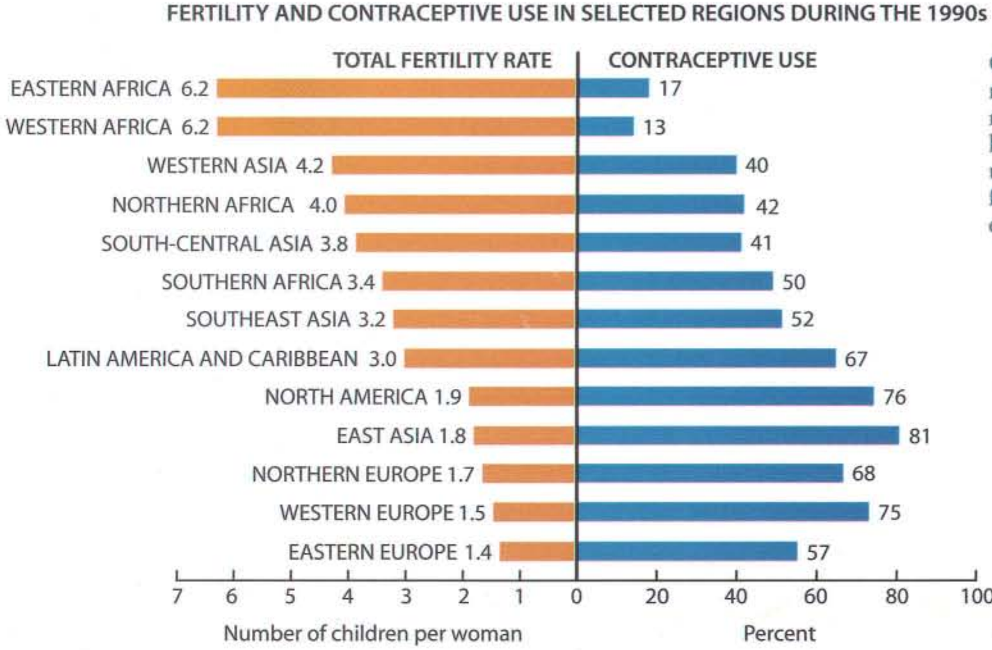
Obstacles to Progress

The trouble is that in some parts of the world contraceptives are either too expensive or simply unavailable to the people who most need them. The female condom, a recent development, may prove too costly for use in the most impoverished regions. I have seen women in Sri Lanka who were eager to control their fertility but so poor that they had to buy oral contraceptive tablets five at a time rather than in a monthly pack of 21. An estimated 120 million couples in developing countries do not want another child soon but have no access to family-planning methods or have insufficient information on the topic. Consequently, pregnancy too often brings despair instead of joy.

Limiting family size can be difficult. A healthy woman may be fertile between the ages of 12 and 50, and men produce viable sperm from puberty until death. Many couples engage in intercourse without taking precautions because they cannot find or afford contraception. For others, sex can be a violent act that leaves a woman with no opportunity to protect herself against unwanted pregnancy. A survey conducted in 1998 in the Indian state of Uttar Pradesh found that 43 percent of wives had been beaten by their husbands. If such women are to be helped, contraceptives have to be very easy to get.

In many countries, laws create hurdles. Japanese women were until this past year forbidden access to the pill and so had to rely heavily on abortion. Until the early 1990s, condom sales in Ireland were restricted to certain outlets, and

FERTILITY AND CONTRACEPTIVE USE IN SELECTED REGIONS DURING THE 1990s

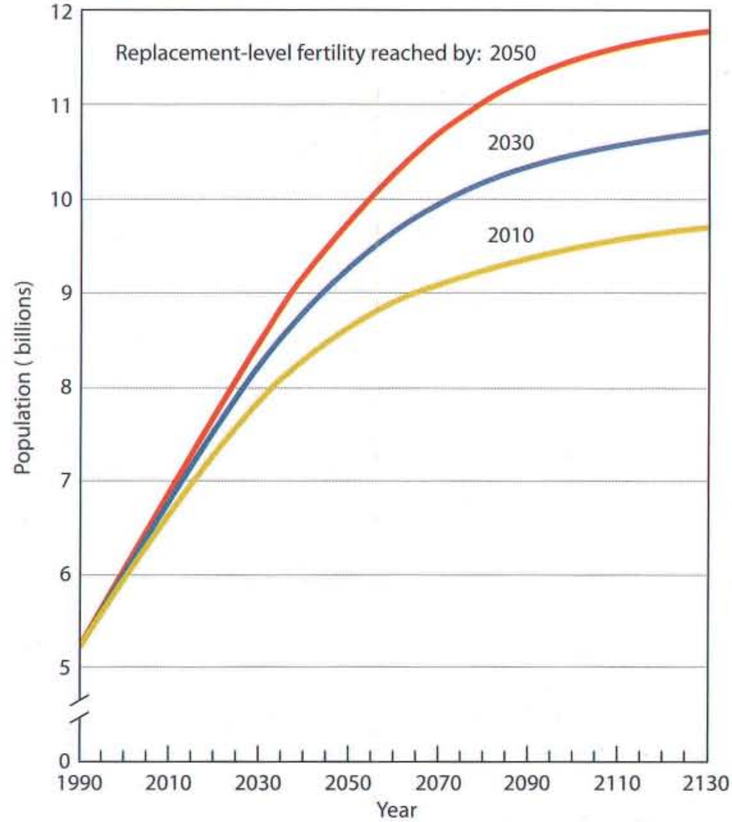


SARAH L. DONELSON; SOURCE: BUREAU OF THE CENSUS/USAID

CONTRACEPTIVE USE has a marked effect on the average number of children that women have. Fertility rates are conspicuously lower in regions where family-planning assistance is easy to obtain.

FUTURE SIZE OF WORLD POPULATION depends critically on how soon it reaches replacement-level fertility, the point at which each woman bears on average about 2.1 children. Projections indicate that faster progress toward lowering fertility could have a large impact.

ULTIMATE WORLD POPULATION SIZE UNDER DIFFERENT ASSUMPTIONS



SARAH L. DONELSON; SOURCE: CARL HAUB, POPULATION REFERENCE BUREAU

even today some pharmacists refuse to sell them. The Indian government does not allow injectable contraceptives to be used, although the method has proved popular in neighboring Bangladesh. The rich typically have ways to get around such obstacles, but the poor do not.

In some nations, contraceptives are available only by medical prescription. This means that they cannot reach the many villages in Asia and Africa where there are few or no doctors. In Thailand, large numbers of women started to use birth-control pills as soon as nurses and midwives were given the authority to distribute them. Restrictive medical practices limit family-planning choices and make contraception more expensive but add nothing to safety. Birth-control pills are safer than aspirin. The world would be a healthier place if oral contraceptives were available in every corner store and cigarettes were limited to prescription use.

Changes in South Korea and the Philippines present a stark example of how family size plummets when consumers are offered a range of appropriately priced contraceptive options through convenient channels. In 1960 families in both countries had an average of about six children. By 1998 fertility had fallen to 1.7 in South Korea. In the Philippines, though, fertility was still 3.7, because family-planning help is harder to get there. Economic research strongly suggests that small family size is a prerequisite to higher per capita income. The difference in fertility rates between South Korea and the Philippines thus probably goes a long way toward explaining why income in South Korea reached $10,550 per person in 1998, whereas in the Philippines it was only $1,200.

In Colombia, fertility fell from 6 to 3.5 in only 15 years after contraceptives became widely available in 1968. In Thailand the same jump took a mere eight years. That identical transition took the U.S. almost 60 years, from 1842 to 1900: anti-vice activist Anthony Comstock persuaded Congress to restrict sales of contraceptives in 1873, and it was not until 1965 that the Supreme Court struck down the last laws banning contraception. No surveys of desired family size were conducted in the U.S. in the 19th century, but I suspect that many couples had more children than they intended.

The contrasting cases of Bangladesh and Pakistan illustrate particularly well how family planning can help women escape centuries of obedience to their mothers-in-law and of subservience to their husbands. Until a civil war in 1971, these two countries were a single political unit, and women had an average of seven births. Over the past 20 years, Bangladesh has made a systematic effort to provide a variety of fertility-regulation methods, including the pill and injectables. With these, women can control whether or not they become pregnant—an advantage they may lack if they rely on their husband's use of a condom. As a consequence, in spite of appalling poverty, fertility has fallen to 3.3 as contraceptive use among Bangladeshi women has risen from 5 percent in the 1970s to 42 percent today. Similar changes have not occurred in Pakistan, where most of the population still does not have access to fertility regulation, and women there bear an average of 5.3 children. These differences will have consequences that will last well into the 21st century. Although Bangladesh will increase its numbers by 65 percent by 2050, Pakistan will probably by then have reached 2.2 times as many people as it has today.

Offering Choices

My lifetime has seen the most far-reaching demographic changes in history. Global population has almost tripled since I was born in 1935; it has quadrupled during the past century. The primary reason is a welcome decline in infant and child mortality brought about by the spread of public health measures such as vaccination. Unfortunately, this progress has not been accompanied by a parallel spread of modern contraception.

It is only since the 19th century that families have routinely seen more than two children survive to the next generation—otherwise there would have been a population explosion centuries ago. Large families are a recent, and temporary, anomaly. Small families reduce stress on the environment, benefit economies—and gain directly themselves. Research in Thailand has shown that children born into families with two or fewer offspring are more likely to enter and stay in school than are children from larger families of four or more youngsters. When pregnancies are spaced at least two years apart, both mother and baby are significantly more likely to survive. Worldwide, one woman dies every minute as a consequence of pregnancy, childbirth or abortion. Some 99 percent of these deaths are in developing countries. Better access to contracep-

tion would reduce this toll substantially by saving on the order of 100,000 women's lives a year.

When Paul Ehrlich wrote his well-known book *The Population Bomb* in 1968, Western governments were just beginning to support family planning in countries such as South Korea. At the time, demographers and politicians spoke about "population control," giving the impression that rich countries were telling others how their people should live. Today we know that the surest way to bring down the birth rate is to listen to what people are asking for and to offer them a range of choices. Adults are capable of making up their own minds about what they want.

Many people in the developing world can afford a small payment for modern contraceptives, but poor countries cannot meet the full cost of manufacturing, distributing and promoting them. A few governments, such as those of India and Indonesia, provide contraception free or at subsidized prices. Yet many nations are too impoverished or too corrupt to make family planning a priority. For many of the hundreds of millions of people around the world who live on a dollar a day or less, donations from rich countries are essential—and wanted.

This consensus achieved public prominence in 1994, when the United Nations organized the International Conference on Population and Development in Cairo. The program agreed to at Cairo broadened the traditional scope of population activities to include not only family planning but also efforts to reduce maternal mortality, to treat sexually transmitted infections and to slow the spread of AIDS. The price tag foreseen for the year 2000 was $17 billion, of which $6.5 billion (in 1998 dollars) was to come from developed nations.

Will that money be available? Not on present showing. In 1998 the total flow of foreign aid from rich to poor countries was the lowest in 30 years. Of this amount, only about 3 percent was allocated to assist family planning and reproductive health. Indeed, the U.S. has cut its funding for international family-planning programs over the past few years.

Developed countries last year provided only one third of the money they had pledged to give at Cairo. Because of the shortfall, even meeting the growing cost of contraceptives and of antibiotics to treat sexually transmitted diseases will be difficult in some places.

Counting the Unborn

Many of the parents of the 21st century's children are already born, so credible estimates of the future world population can be made to about 2050. The latest projections from the U.N. Population Division, issued in 1998, envisage a global total between 7.3 billion and 10.7 billion in 2050, with 8.9 billion considered the most likely figure.

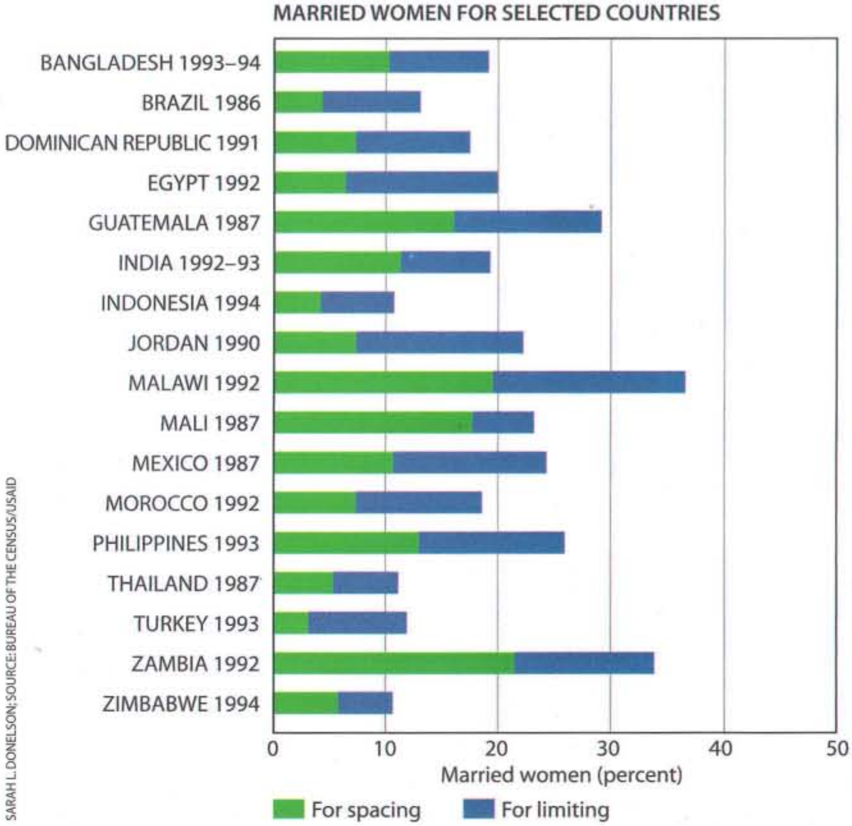
It is crucial to realize, however, that this "most likely" number assumes a continuing rise in the rate of use of contraceptives and consequent widespread decline in birth rates. Specifically, it supposes that fertility in developing countries will reach 2.1 by 2050. With current trends, this actually seems unlikely. Large regions of Africa and southern Asia have fertility rates far above 2.1, and unless more funds for family planning become available, I see no reason to think fertility will fall as much as the U.N.'s "most likely" figure assumes.

The 1998 projections necessarily take account of the relentless spread of the AIDS virus in many countries. It now seems probable that well over 50 million people will be infected by 2010—roughly comparable to the number of combatants and civilians killed in World War II. AIDS has lowered average life expectancy by seven years in the 29 most affected African countries. Yet despite this devastating impact, the population of Africa is set to grow from 750 million today to more than 1.7 billion in 2050 because of the momentum built into the population's youth-heavy age structure.

Population projections are not predictions but "what if" statements. If support for family planning remains inadequate, three possibilities, not mutually exclusive, suggest themselves.

First, birth rates could remain higher than the U.N. assumes they will in its projections. Small variations in the rate at which fertility declines in the next few decades will have profound consequences well into the 22nd century. For example, if Nigeria, now at a population of 114 million, were to achieve a replacement-level fertility of 2.1 in 2010, its population would stabilize at 290 million in about 2100. If the country did not reach 2.1 children for each woman until 2030, the population would rise to 450 million, corre-

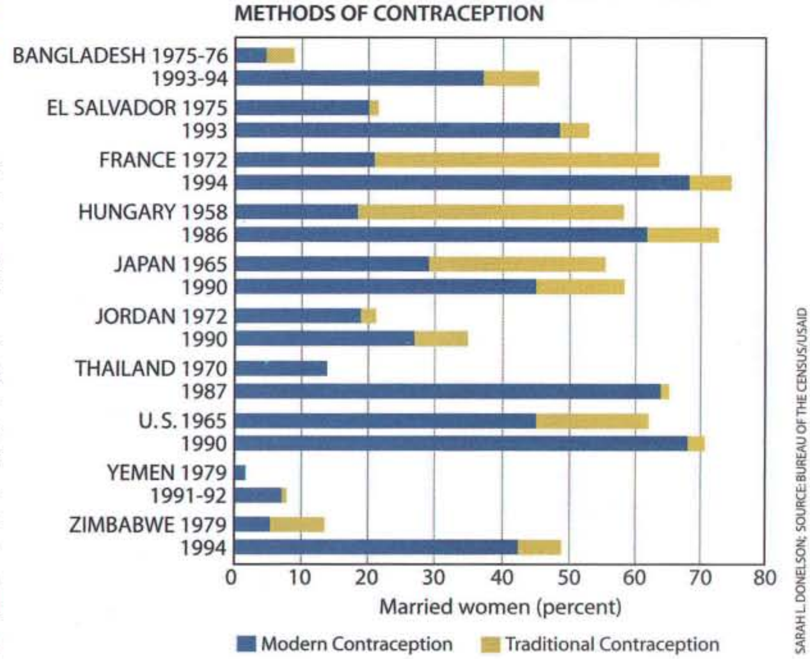
UNMET NEED FOR FAMILY PLANNING AMONG MARRIED WOMEN FOR SELECTED COUNTRIES



SARAH L. DONELSON; SOURCE: BUREAU OF THE CENSUS/USAID

MANY WOMEN in low-income countries say they would use family-planning services if these were easily available. Some indicate that they would limit the size of their families; others would use the help to space their pregnancies further apart.

USE OF CONTRACEPTION has increased around the world. In addition, more women are employing modern methods, as compared with traditional techniques such as coitus interruptus and abstinence. Yet large disparities between richer and poorer countries persist.



sponding to a population density 40 percent greater than that of the Netherlands today. If replacement-level fertility does not arrive until 2050, Nigeria's population could theoretically reach 700 million. In fact, disease or starvation would limit population in a most inhumane way long before then.

The second possible outcome of a failure to expand family planning is that some governments might be tempted to impose strict population-control measures such as those adopted by China. In the 1950s and 1960s Mao Tse-tung encouraged large families for ideological reasons. (The Taiwanese, who had excellent access to contraceptives, had one of the quickest fertility declines in history.) By the time the Chinese woke up to the need to slow their growth in 1979, the momentum was so great that the state felt compelled to limit couples to just one child. Even with this policy, the number of Chinese grew from 989 million in 1979 to 1.25 billion today—a gain only slightly less than the total population of the U.S., in a country of roughly the same size.

A third possibility is that abortion rates may rise. Each woman around the world now averages one induced abortion in her lifetime. A recent calculation based on African data suggests that if contraceptives are not available to meet the growing demand, a sixfold jump in abortions will be necessary for birth rates to fall in line with the U.N. assumptions. That sort of jump would kill thousands of women, because abortions are often performed unsafely.

The success or failure of national family-planning efforts in the opening years of the coming millennium will divide the world along a new geopolitical fault line. Those newly industrialized nations of Asia and Latin America that see family size settle at two or fewer children by about 2010 will join the club of rich Western nations. They will have a slowly aging population, and the number of their citizens older than 60 will double by 2050.

The other set of countries, in Africa and the Indian subcontinent, will be overwhelmed by burgeoning population growth. Vast cohorts of young people will grow up with little education and even fewer job opportunities. Some may form gangs in politically unstable, exploding city slums; others may try to eke out a living by cutting down the remaining forests.

The Cairo conference recognized "the crucial contribution that early stabilization of the world population would make towards the achievement of sustainable development." Transforming the global economy into a biologically sustainable one may well prove the greatest challenge humanity faces. Ultimately, we have to construct a world in which we take no more from the environment than it can replace and put out no more pollution than it can absorb.

If this transition is to succeed, societies will have to reduce both levels of consumption and population sizes. Even today it would be impossible for the planet to sustain a Western standard of living for everyone. Many experts predict that a billion people will be facing severe water shortages by 2025.

Fortunately, much expertise has accumulated about how to make family planning available. The cost to developed countries of meeting this vital need is less than $5 per person per year. That amount is trivial in comparison with the financial, environmental and human costs of inaction. SA

The Author

MALCOLM POTTS is a British physician who also holds a doctorate in embryology, which he earned at the University of Cambridge. For the past 30 years, he has worked with a variety of groups in the design and implementation of family-planning services and in AIDS prevention. He is a board member of Population Services International, among other organizations, and the author or co-author of several books on aspects of human fertility. Last year Potts published *Ever Since Adam and Eve: The Evolution of Human Sexuality.* He is Bixby Professor in the School of Public Health at the University of California, Berkeley.

Further Information

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by Shawn Carlson

Detecting Extraterrestrial Gravity

Every Sunday morning I enjoy a walk along a two-mile stretch of the world's most sensitive gravimeter. The sun's and moon's gravitational tugs on my body amount to only a few millionths of the earth's, and yet that tiny force acting over the Pacific Ocean regularly raises the sea level so high as to batter my path with waves. But isolating these feeble forces inside a laboratory tasks even professional instruments. That's why I was astonished to learn that Roger Baker of Austin, Tex., has developed a device that can gravitationally track the position of the sun and moon—for about $100.

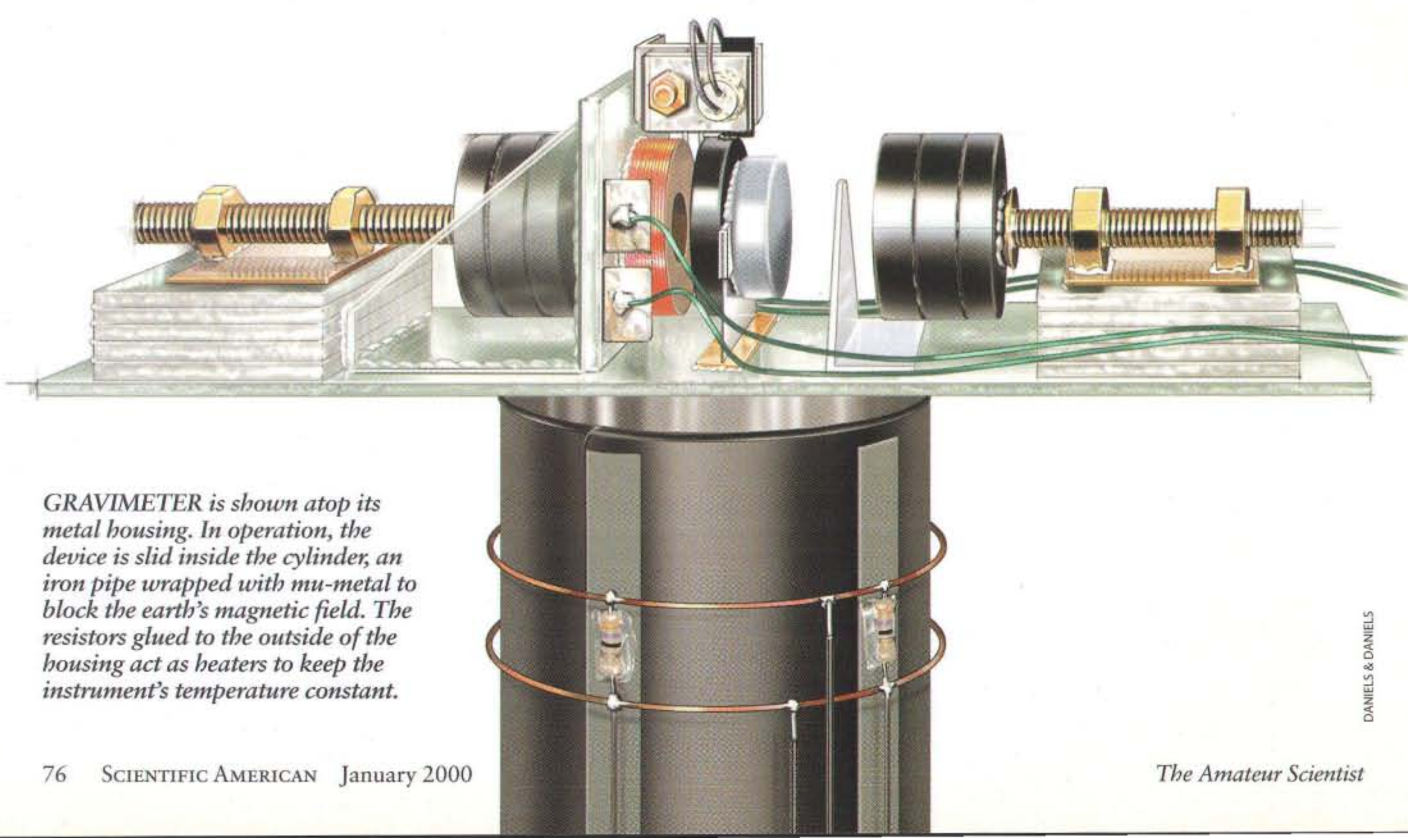
One of my favorite truisms of science asserts that yesterday's discovery is today's calibration and tomorrow's noise. That is particularly applicable here. Last January I described another Baker invention that can detect micropulsations in the earth's magnetic field. But even these minute magnetic effects would swamp the gravitational forces that we are trying to measure here. In fact, eliminating all the spurious influences is by far the most challenging part of this project, and success depends on experience. Only expert gadgeteers should attempt it.

In Baker's apparatus, a small but powerful magnet delicately floats between two permanent magnets. A clever optical device senses small movements caused by gravitational shifts, seismic activity, thermal expansion, a stomping toddler and so on. A control circuit counters the motion by fine-tuning the current through an electromagnet. Changes in this current thus track forces acting on the floating magnet. The float is weighted to make it insensitive to high-frequency motion. But it does capture slowly oscillating signals from earthquakes (with undulations of a few tens of hertz) and the changing position of the moon as the earth turns on its axis. In fact, Baker originally designed the instrument as a vertical-motion seismograph.

The optical sensor accounts for much of the instrument's sensitivity. To monitor the float's position, it uses an opaque flag to block some of the light from an LED and keep it from reaching a phototransistor a few millimeters away. When the float and flag move, the light signal changes quickly; shifts in position on the order of a nanometer have a discernible effect.

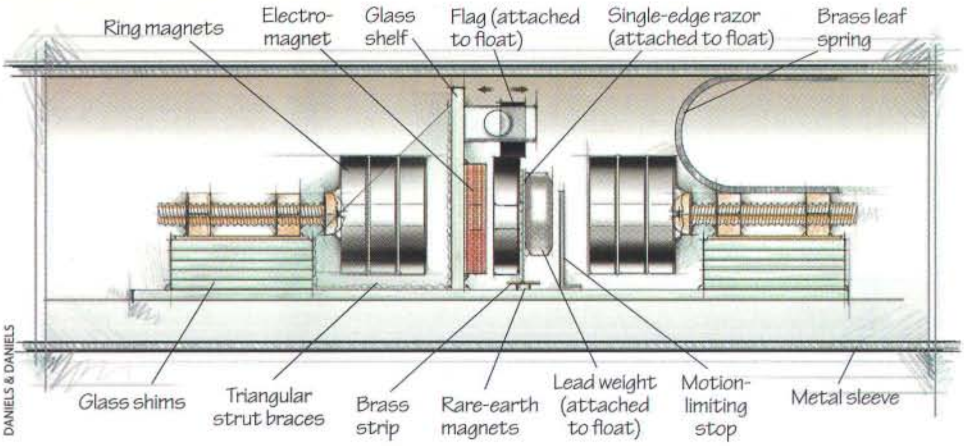
Radio Shack sells ceramic magnets in sets of five for about $2 (part no. 64-1888). You'll need two sets for a total of 10 ring magnets. Stack six of them into two groups of three and epoxy them to bolts [*see illustration at top of opposite page*]. The seventh magnet will serve as the float; the other three are unneeded. Baker keeps the float from moving sideways by attaching it to a steel razor blade. The sharp edge of the razor will abut a brass plate on the side of the instrument support. Two miniature rare-earth magnets (Radio Shack part no. 64-1895) behind the plate fix the razor's edge to the brass. A smear of oil along the blade creates an almost frictionless hinge that allows the float to swing up and down but not side to side. Finally, Baker attaches a one-ounce lead fishing weight to lower its natural frequency and the small opaque flag to sense its position.

Although you can build the gravimeter frame out of any nonmagnetic material, Baker recommends using window glass



GRAVIMETER is shown atop its metal housing. In operation, the device is slid inside the cylinder, an iron pipe wrapped with mu-metal to block the earth's magnetic field. The resistors glued to the outside of the housing act as heaters to keep the instrument's temperature constant.

DANIELS & DANIELS



BAKER'S GRAVIMETER, shown in horizontal cross section, can register extremely small movements caused by gravitational pulls. (In practice, the device is mounted vertically.)

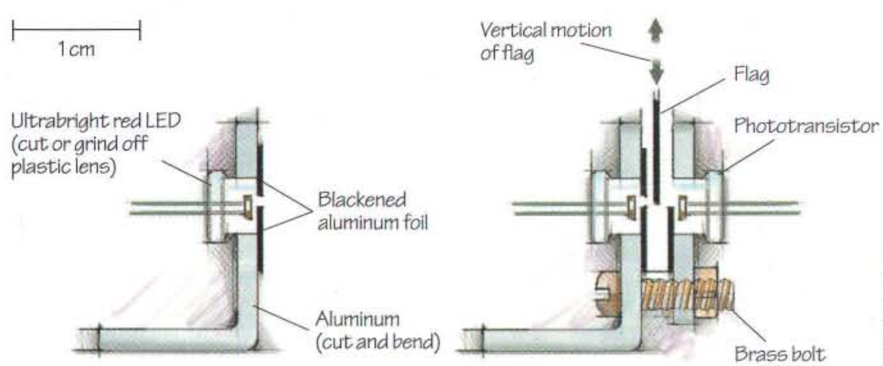
because of its low cost, low thermal expansion and ease of assembly. He cuts the plates with a carbide-wheel glass cutter so that the pieces fit together without gaps and then braces the structure with triangular glass supports. He glues them all together with silicone cement. Mistakes are easy to fix because the parts can be readily separated with a razor blade.

For the electromagnet, Baker winds a coil utilizing two of the unused ceramic magnets as guides. Wrap a pencil with masking tape until the magnets slide onto it snugly. Cover the magnets with more masking tape and position them about one magnet diameter apart on the pencil. Then tape one end of 30-gauge enameled magnet wire (Radio Shack part no. 278-1345B) to the edge of one of the disks and begin wrapping the wire between them. Keep a few ounces of tension on the wire and continuously coat it with 24-hour epoxy as you go. Don't stop until the coil's edge is about two millimeters below the edges of the magnets. After the epoxy sets, warm the assembly in an oven at a low setting to melt away the masking tape adhesive, then separate out the bare coil. The finished coil will be about 0.5 centimeter long and 2.7 centimeters in diameter. Its DC resistance should be about 10 ohms.

The optical position sensor requires some care. You can use an ultrabright red LED (Radio Shack part no. 276-066B) and a phototransistor (part no. 276-145A), but you'll need to eliminate the outer cases to bring the active elements as close together as possible. Grind the casings down to the chips and then polish the ends with a fine-grit polish. A combination of toothpaste and elbow grease applied against the back side of a piece of soft wood works well. Install the circuit elements into their frames with silicone cement [*see illustration below*]. Next, blacken three small pieces of aluminum foil with a felt-tipped marker. Carefully epoxy two of them to the LED so that they form a narrow horizontal slit; Baker says his slits are about half a millimeter wide. Use the third piece to block the bottom half of the phototransistor. This trick sharpens the device's sensitivity because it causes the signal to crash rapidly to zero as the flag cuts across the narrow beam of light emerging from the slit. Assemble the rest of the instrument as shown.

Like almost all delicate instruments, Baker's gravimeter will produce spurious results if its temperature changes. Baker solved that problem by controlling its temperature. He installed the detector inside a metal sleeve, which he kept at about 10 degrees Celsius above room temperature by employing twenty 50-ohm $1/2$-watt resistors as small heating elements. Baker sensed the temperature using a Radio Shack thermistor, the output of which he compared with an adjustable set-point voltage, determined by a potentiometer. A circuit turns on the current through the resistors whenever the thermistor signal is below the set point and turns them off when the signal climbs above it. This setup, simple though it is, can keep the temperature constant to within a few hundredths of a degree C.

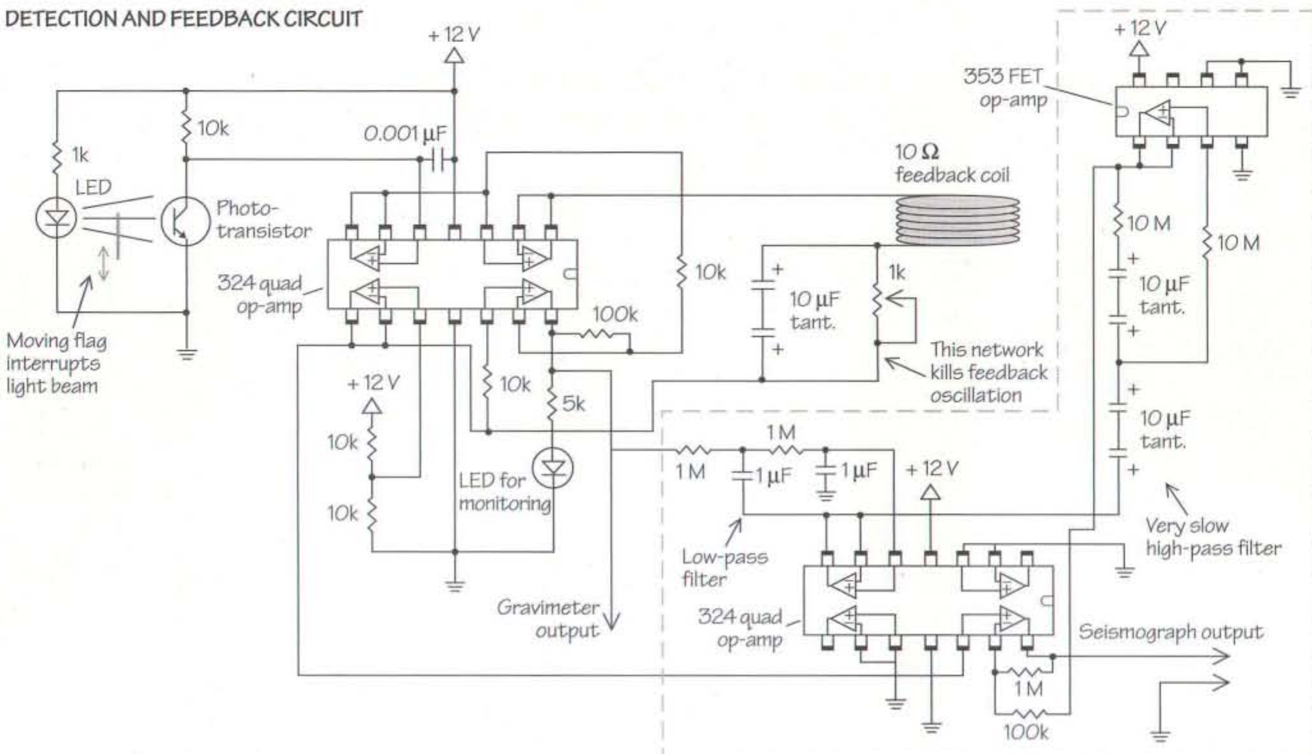
The metal sleeve also serves to shield the apparatus from the earth's magnetism. It consists of an iron water pipe, three or so inches in diameter and eight inches long, wrapped with layers of thin foils made of mu-metal or permalloy interposed with sheets of a nonmagnetic material such as cardboard. You can purchase mu-metal foil through the Society for Amateur Scientists for $30 per square foot. In any case, the shield needs to extend at least two pipe diameters beyond both the top and bottom of the detector to attenuate magnetic fields that enter through its open ends.



OPTICAL SENSOR, which can detect nanometer shifts in position, consists of an LED* (left) *facing a phototransistor, with an opaque flag that cuts the light beam between them* (right). *The beam passes through a narrow slit in the aluminum foil.

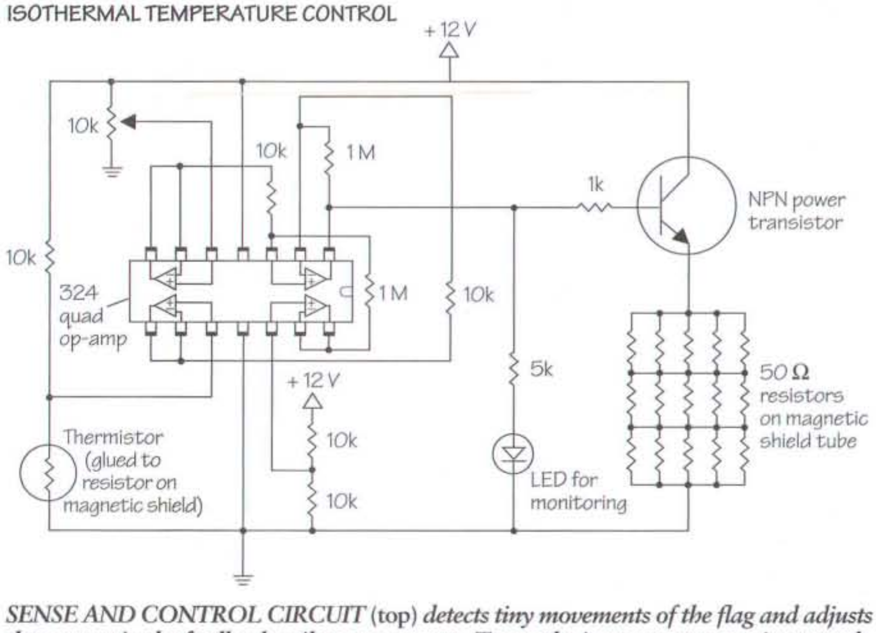
To monitor the forces on the detector, you'll need to connect it to a computer. Baker uses the WinDAQ analog-to-digital converter, which runs from the Windows operating system. The WinDAQ/Lite sells for about $100 (contact www.dataq.com). Macintosh aficionados should check out the Serial Box Interface from Vernier Software (www.vernier.

DETECTION AND FEEDBACK CIRCUIT



JOHNNY JOHNSON

ISOTHERMAL TEMPERATURE CONTROL



SENSE AND CONTROL CIRCUIT (top) *detects tiny movements of the flag and adjusts the current in the feedback coil to compensate. To use the instrument as a seismograph, add the filters as shown. The temperature control circuit* (above) *can maintain the sensor's temperature to within one hundredth of a degree Celsius.*

com). There are, of course, other options. For this application, the computer should display the data like a chart recorder, showing the shifting voltage across the coil versus time.

Install the instrument vertically on a stable base and set it on a concrete foundation as far from car and foot traffic as possible. Turn on the power and let the heater warm up. Then remove the insulation from the top and adjust the screw that raises and lowers the upper magnet while watching the output and find the location at which the signal from the phototransistor just barely turns on. This is an extremely tricky operation. At this point, a slight movement would turn the signal completely on or off. The float will naturally bob up and down at a frequency of about one second, which should be apparent on an oscilloscope. Replace the insulation.

For fine adjustments, rest a ceramic magnet on top and move it around until the signal from the phototransistor just dims. The instrument should now record for weeks with only occasional adjustments to the outer magnet necessary to maintain its high sensitivity. If you are really observing extraterrestrial gravity, you should see a slowly varying sine wave that is in phase with your local tides. The detection will be less ambiguous if you live far from the shore so that secondary effects, such as swelling of the beach, do not account for the signal. Ambitious graviteers can carry out a Fourier transform on the data and look for excess power at around a period of 24 hours and also at 28 days. SA

You'll find more information about this project on Roger Baker's Web site at www.eden.com/~rcbaker. Please send your questions directly to the Society for Amateur Scientists through the ongoing discussion at earth.thesphere.com/sas/WebX.cgi. As a service to the amateur community, the society is selling the electronic components only (not the circuit board) for this project for $50 until December 2000. Mu-metal shielding is extra. You may write to the society at 4735 Clairemont Square, PMB 179, San Diego, CA 92117, or call 619-239-8807.

by Ian Stewart

Impossibility Theorems

In ordinary discourse when we say something is impossible, we often don't mean that. What we mean is that we can't see any way to achieve it. Many people once thought it was impossible for machines heavier than air to fly, and before that a lot of people thought it was impossible for machines heavier than water to float. Human ingenuity frequently overcomes apparent impossibilities.

In mathematics, though, impossibility is something you can often prove. For instance, 3 is not an integer power of 2. One way to prove this is to ask what power of 2 could equal 3 and observe that 1 is too small ($2^1 = 2$) and that 2 is too big ($2^2 = 4$). Impossibility proofs, however, function only within the world of mathematics as it is currently set up: if you change the rules of the game, different things may happen. For example, in the set of integers "modulo 5," any multiple of 5 is considered to be 0 and any number above 5 is converted to the remainder after division by 5. Under these rules, $3 = 2^3$. This doesn't mean that my original impossibility statement is wrong, because the context has been changed. It just means I have to be careful to define what I'm talking about.

This ability of mathematics to prove certain tasks impossible has a frustrating side effect. Imagine that I have spent the past 10 years filling notebooks with calculations, and I convince myself that I have discovered a new prime number, several thousand digits long. Unlike any other known prime, though, this one is even. Its final digit, in ordinary decimal notation, is 6. Excited beyond measure by this amazing feat, I send my work to a mathematician, who immediately sends it back again, telling me that it's nonsense. Worse, when I ask him where I've made a mistake, he says he hasn't read my work and he has no idea where the mistake is but that he knows there must be one. I am appalled: what arrogance!

In most areas of everyday life, that would indeed be arrogance. But in mathematics, it is no more than a simple application of logic. The only even prime number is 2. There are no others.

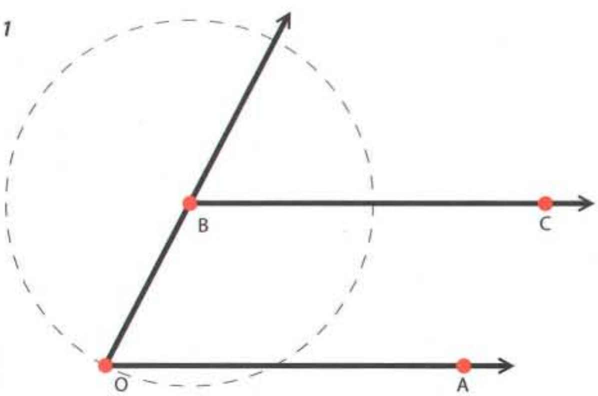
One of the most profound impossibility theorems was introduced in the early 19th century by two mathematicians working independently: Niels Henrik Abel of Norway and Évariste Galois of France. Using different methods, each proved that the general equation of the fifth degree cannot be solved by a formula involving only the ordinary operations of algebra and the extraction of radicals—that is, square roots, cube roots, fourth roots and so on. Earlier mathematicians had discovered formulas in radicals to solve less complex equations: the familiar quadratic formula solves equations of the second degree, and similar expressions exist for equations of the third and fourth degrees. But all attempts to find a corresponding formula for equations of the fifth degree failed. Abel and Galois put a stop to such attempts by proving that they could never succeed.

To see how such proofs are possible, consider a well-known puzzle. A chessboard has 64 squares. If you take 32 dominoes, each formed from two squares the same size as those of the chessboard, there are enormously many ways to tile the board with dominoes [*see illustration on opposite page*]. If you remove two adjacent corners, you can easily tile the result with 31 dominoes. If you remove two diagonally opposite corners of the board, however, all attempts to tile the result with dominoes fail.

Do your repeated failures prove that the task is impossible? No, not even if you spent a lifetime trying. Is the tiling impossible? Yes, and here's the proof: if you fit a domino on a chessboard, it always covers one black square and one white one. So if you tile a board with dominoes, the number of white squares must be equal to the number of black squares. This is the case for the first two boards but not for the one with oppo-

***TRISECTING AN ANGLE** is possible if you use a compass and a marked ruler. Draw a circle centered at B that passes through O, and draw a line BC parallel to OA* (1). *Mark X and Y on the ruler so that XY = OB* (2). *Slide the ruler so that it passes through O, X is on the circle and Y is on BC* (3). *Then angle AOY is one third of angle AOB.*

1



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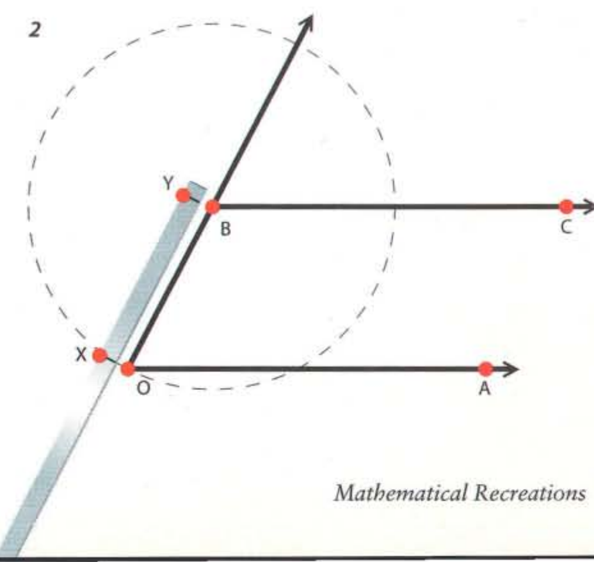


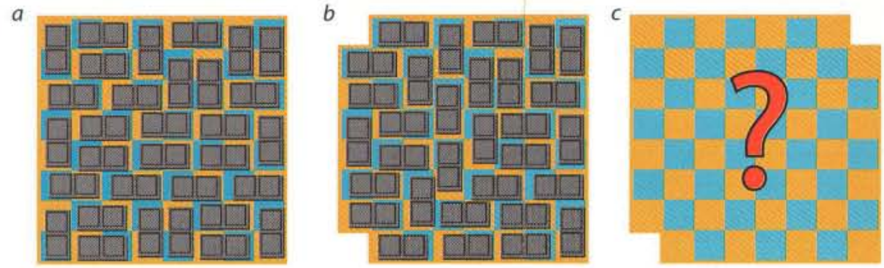
BRYAN CHRISTIE

site corners removed, which has 30 squares of one color and 32 of the other.

This proof has a basic element in common with Galois's proof of the insolubility by radicals of equations of the fifth degree. (Abel's proof does not fit quite so neatly into this framework.) Both arguments involve the introduction of an invariant—a feature of a hypothetical solution that can be calculated without knowing the detailed form of that solution. For the domino problem, the invariant is a simple one: the equality of black and white squares. For the fifth-degree equation, it is a sophisticated algebraic feature of the symmetries of the roots of the equation, called the Galois group. If the invariant does not fit the conditions of the problem, then any proposed solution must fail. And you can know this without even seeing the proposed solution!

Similar impossibility theorems can be found in another popular area of recreational mathematics: the construction of geometric figures. In the simplest constructions you are permitted to use only an unmarked ruler and a pair of compasses. The construction starts from some known set of points and successively locates new points as intersections of lines or circles. Any lines drawn must join known points, and any circles must be centered on a known point and pass through another known point.

What mathematical problems can be solved using such constructions? You can, for example, divide a given line segment into any specified number of equal pieces. You can also divide a given angle into two equal angles—that is, bisect the angle—and, by repeating the procedure n times, into 2^n equal angles. You can



BRYAN CHRISTIE

DOMINO TILINGS are possible for a 64-square chessboard (a) *and for a board with two adjacent corners removed* (b). *But can you tile a board that is missing two diagonally opposite corners* (c)*?*

draw regular polygons with 3, 4, 5, 6, 8, 10 and 12 sides. All this has been known since the time of Euclid. Over the next two millennia, many mathematicians tried to use the same method to solve three other simple-looking problems:

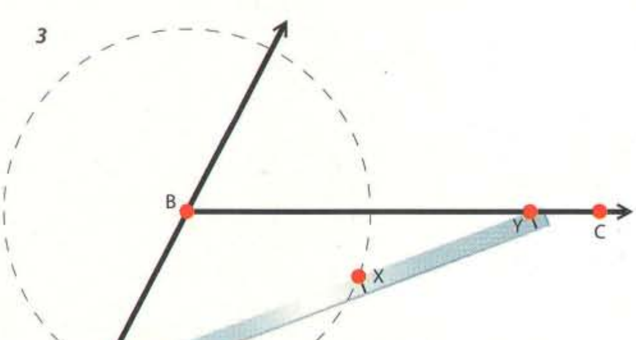
- Constructing a cube whose volume is twice that of a given cube.
- Trisecting a given angle (cutting it into three equal pieces).
- Constructing a square whose area is equal to that of a given circle.

We now know why mathematicians had so much trouble with these problems: all three are impossible to solve using ruler-and-compass constructions.

We are seeking exact solutions here, not approximations—it is straightforward to make all three constructions to any required degree of approximation. Furthermore, we cannot employ other instruments besides the unmarked ruler and compasses. Using a marked ruler makes it simple to trisect an angle [*see illustration on opposite page*].

What is the invariant for ruler-and-compass constructions? Any such construction can be represented in coordinate form and corresponds to the calculation of a sequence of numbers—the coordinates of the points involved. Every step in the construction introduces coordinates that are related to the known ones by an equation of either first or second degree (first for line-meets-line steps, second if a circle is involved). This means that the "degree" of any point in the construction—the lowest-degree equation for which it is a solution—

3



must be a power of 2. This is the simplest invariant for ruler-and-compass constructions, and it is good enough to kill off all three of the problems listed above.

Duplicating the cube is equivalent to solving $x^3 - 2 = 0$, which is a third-degree equation. Because 3 is not a power of 2, the cube cannot be duplicated using ruler-and-compass constructions. Trisecting an angle is also equivalent to solving an equation of the third degree. (This follows from trigonometry and the equation $\cos 3x = 4(\cos x)^3 - 3\cos x$.) So this problem is also impossible to solve.

Squaring the circle is equivalent to finding a second-degree equation that is satisfied by π. According to a theorem proved by 19th-century German mathematician Ferdinand Lindemann, however, π cannot satisfy any such equation, because the number cannot be expressed as a finite series of algebraic operations.

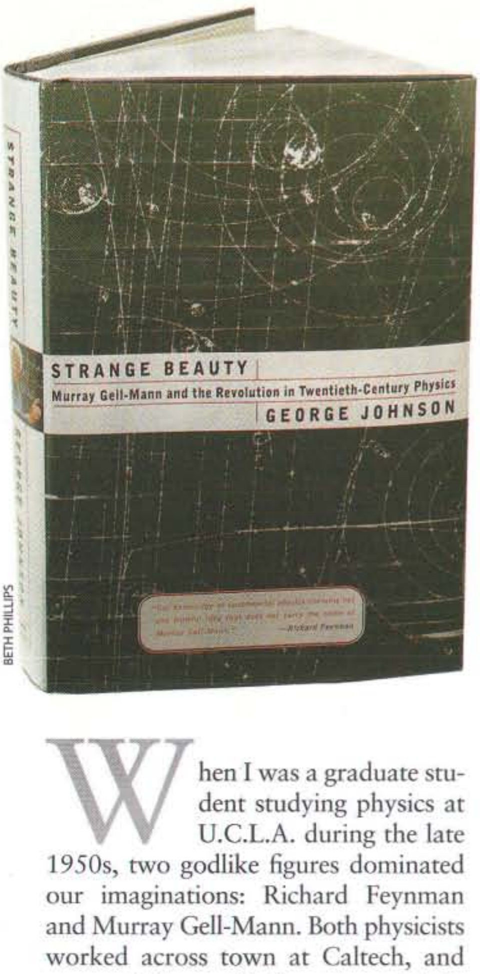
This, then, is how we know that it is a waste of time to try to solve these problems using an unmarked ruler and compasses. Unfortunately, the existence of an impossibility proof often doesn't stop people from trying to solve the problems. Underwood Dudley's fascinating book *The Trisectors* (Mathematical Association of America, 1994) records many such attempts. The sad thing is that trying to trisect the angle with an unmarked ruler and compasses is just as pointless as trying to prove that 3 is an integer power of 2.

By the way, for all you trisectors out there: any such attempts will not be considered for Feedback, for the reasons just outlined. Send them to Woody Dudley, who collects them. But I'd be interested to hear of any clever gadgets for trisecting angles—or any especially neat approximate constructions—because I know those are possible. SA

AN IRRESISTIBLE SUBJECT

Review by Chet Raymo

Strange Beauty: Murray Gell-Mann and the Revolution in Twentieth-Century Physics
BY GEORGE JOHNSON
Alfred A. Knopf, New York, 1999 ($30)



BETH PHILLIPS

When I was a graduate student studying physics at U.C.L.A. during the late 1950s, two godlike figures dominated our imaginations: Richard Feynman and Murray Gell-Mann. Both physicists worked across town at Caltech, and now and then we'd slip over and sit in on a lecture. Feynman was the older of the two and better known, as much for his wry wit as for his stunning work on quantum electrodynamics. Who was smarter, Feynman or Gell-Mann? On the street, the choice was up for grabs.

Some folks are just a lot smarter than the rest of us, and Feynman and Gell-Mann were about as smart as you get. The very existence of such towering geniuses just down the road had a mixed effect on us students. Some were inspired to compete with the greats; others inclined toward melancholy. If nothing else, it was an exciting time to be entering an exciting field, and the two Caltech paragons were a big part of the excitement.

Feynman knew everything there was to know about physics and not much about anything else; when not doing physics, he played the bongos and hung out in bars. Gell-Mann knew everything there was to know about everything, and during "off" hours he was likely to be bird-watching in some exotic venue, collecting archaeological artifacts or picking up yet one more foreign language. At least these are the impressions one gets from George Johnson's masterful biography of the younger member of the dynamic duo. When the two rivals got together, sparks would fly, igniting lots of good physics. Both men would eventually win Nobel Prizes.

Strange Beauty brings together an irresistible subject—the difficult polymath Murray Gell-Mann—and a talented writer who spins an enthralling tale out of the kind of esoteric physics that generally flies right over our heads. Johnson is one of the best science journalists writing today, known for his books *Fire in the Mind* and *In the Palaces of Memory* and for incisive reporting in the *New York Times*. This is his most ambitious project yet—communicating the fascination of a kind of science that only an elite of superbright people fully understands. He succeeds brilliantly.

Of course, it is the strange and beautiful mind of Murray Gell-Mann that is the hero of this tale, and not the least part of Johnson's task was to explain where such a mind comes from. Genes, certainly. Gell-Mann's father, Arthur, an Austrian-born immigrant to New York City, had a gift for languages and mathematics and a kind of loony genius (it was he who put the hyphen in the family name). Mother Pauline was restless, obsessively cheerful, and dreamy. Murray saw his own inheritance as a combination of the Apollonian (detached, rational, analytic) and the Dionysian (intuitive, romantic, involved). Odyssean, he called it. Whatever it was, he was early dubbed a "boy genius."

As children, Murray and his older brother, Ben, would explore the meadows and woodlands of Central Park, identifying birds, insects, mammals and plants. Sitting home on rainy days, the boys studied languages, tracing relationships among the world's diversity of tongues. In both outer and inner worlds Murray made a life-altering discovery: everywhere beneath the world's confusion there was an underlying order.

His educational trajectory took him to Yale, M.I.T., the Institute for Advanced Study in Princeton, N.J., the University of Chicago and eventually, as a young professor, to Caltech, encountering along the way such heroes of midcentury physics as Victor Weisskopf, Robert Oppenheimer and Enrico Fermi. Everywhere his prodigious talents attracted the support of worthy mentors. The attention of physicists at that time was focused on the nucleus of the atom. Protons and neutrons were not the stable building blocks they had once appeared to be. The study of cosmic rays and experiments with high-energy particle accelerators had revealed a zoo of other short-lived particles that flickered in and out of existence. It was as if the floor of the house of physics and chemistry had fallen away, displaying a bewildering maze of subbasements.

Patterns of Order

Strange Beauty is the story of the search for patterns of order in this proliferation of exotic particles. The title comes from one of Gell-Mann's favorite quotes from Francis Bacon: "There is no excellent beauty that hath not some strangeness in the proportion." Strangeness is the name Gell-Mann gave to a new quantum number he invented to impose order on the shower of "strange" particles that came streaming down from cosmic-ray collisions in the upper atmosphere, supplementing familiar quantum numbers such as mass, momentum, charge and spin. This was the first of three extraor-

dinary contributions he made to sorting out the excellent beauty of nature, the others being the "Eightfold Way," an elegant scheme of particle classification, and quarks, a family of sub-subnuclear particles of fractional charge. Gell-Mann not only had a gift for physics, he also had a knack for nomenclature.

Strange Beauty weaves three threads. One is the story of Gell-Mann, brilliant, cantankerous, energetically in love with the strange beauty of nature. The second is the story of physics in the latter half of the 20th century, a descent into those subbasements of matter that sometimes seems to take physicists further and further from the world of ordinary experience. The going is tough, but Johnson is an excellent guide. The third and perhaps most interesting part of the book asks, "What does it all mean?" It is to Johnson's credit that he tackles the philosophical questions head-on.

Do scientists invent the world or discover it? What is the basis for the extraordinary success of mathematics as a language of invention/discovery? Does nature indeed have fundamental patterns of order—a bottom floor, simple and firm, with no more steps descending—or is nature an endless house of mirrors, a multidimensional maze of illusions and self-deceptions? What is reality? Is there such a thing?

According to Johnson, Gell-Mann was never particularly interested in metaphysical questions. They were distractions from the thrill of teasing out the origins of nature's manifest beauty. "For me the two things are inseparable," he once said, "the love of the beauty of nature and the desire to explore further the symmetry and subtlety of nature's laws." Those laws, he firmly believed, reflect a world that is made of crystallized mathematics. Like many physicists of the late 20th century, he hoped to find a pattern of mathematical order so self-evidently true that God would have had no choice in making the universe. In the first instant of the big bang, all was symmetry, a hidden transcendent perfection. In the cooling of the universe after the primal explosion, the symmetries had broken, resulting in an apparent chaos of particles and forces (a world in which Gell-Mann's beloved first wife, Margaret, might die tragically of cancer). Hints of the primeval symmetry could be found in the lines and spirals physicists see in their detectors when high-energy particles smash and scatter.

Do scientists invent the world or discover it?

Johnson gives us the skeptic's position, too: "But when the experiments required so many layers of interpretation, how could the physicists know when they were reading too much into the lines and squiggles, seeing what their brains were primed to see, like pictures in the clouds? Were these really discoveries, or inventions?" Whatever one's philosophical inclinations, Johnson says, it is not hard to be in awe of what Gell-Mann and his colleagues accomplished, the so-called Standard Model describing the particles and forces of nature. Discovery or invention, it was a work of high art.

Today Gell-Mann continues his quest for nature's hidden laws, studying complexity and chaos at the Santa Fe Institute, which he helped to found. The new question on his mind seems to be this, in Johnson's words: "How does one get from the symmetries of subatomic particles to the messiness of the world, from unbending equations to the diversity of the rain forest?" Answering that question will illuminate not only the crystalline origin of the universe but also its tangled subsequent history.

As they worked together at Caltech, Feynman and Gell-Mann delighted in "twisting the tail of the cosmos," as they called it. In his Nobel address in Sweden, Gell-Mann described the physicist's work this way: "We are driven by the insatiable curiosity of the scientist, and our work is a delightful game. I am frequently astonished that it so often results in correct predictions of experimental results." Johnson's strangely beautiful book captures the curiosity, the game and the astonishment.

CHET RAYMO teaches physics at Stonehill College in Massachusetts. He is a science columnist for the Boston Globe.

THE EDITORS RECOMMEND

Galileo's Daughter: A Historical Memoir of Science, Faith, and Love. Dava Sobel. Walker & Company, New York, 1999 ($27).

FROM GALILEO'S DAUGHTER

The daughter of the title was Virginia, eldest of Galileo's three children. She spent her adult life in the Franciscan convent of San Matteo, near Florence, as Suor Maria Celeste, a name she chose (according to Sobel) "in a gesture that acknowledged her father's fascination with the stars." From there she carried on a lifelong correspondence with him—doting, supportive, stylish letters. (His side of the correspondence is not to be found; the mother abbess "apparently buried or burned" his letters out of fear of having the convent associated with a man "vehemently suspected" of heresy by the Inquisition.) Galileo greatly admired his daughter, describing her in a letter to a friend in Paris as "a woman of exquisite mind, singular goodness, and most tenderly attached to me." Science writer Sobel, learning that 124 of Maria Celeste's letters survive in the National Central Library of Florence, went there, translated them and made them the basis of this lucid review of Galileo's life and scientific achievements. It is a humanizing approach to the great man and makes for fine reading. The letters, Sobel says, "recolor the personality and conflict of a mythic figure, whose seventeenth-century clash with Catholic doctrine continues to define the schism between science and religion."

The Extraterrestrial Life Debate, 1750–1900. Michael J. Crowe. Dover Publications, Mineola, N.Y., 1999 ($19.95).

Crowe's aim is to show that "the question of extraterrestrial life, rather than having arisen in the twentieth century, has been debated almost from the beginning of recorded history." He deals only briefly with writings before 1750 because they "have recently been capably discussed by Steven J. Dick in his *Plurality of Worlds: The Origins of the Extraterrestrial Life*

Debate from Democritus to Kant," and he stops early in the 20th century because of "the vast quantity of materials that had appeared by then" and also because of "my determination to base this study on firsthand knowledge of the great majority of these items." The extent of his firsthand knowledge is suggested by his bibliography, listing 143 works published from 1584 to 1915, and his name index, which has more than 1,000 entries. Crowe is a professor of philosophy of science at the University of Notre Dame, and one would expect his discussion to range over the philosophical, scientific and religious aspects of his subject. It does. One learns what prominent people in each field have said for or against extraterrestrial life. It is, Crowe writes, a debate that "differs from most debates in the history of science by the fact that it remains unresolved." The book is a reprint of the edition published in 1986 by Cambridge University Press.

SECRET WORLDS. Stephen Dalton. Firefly Books, Willowdale, Ontario, 1999 ($35).

Dalton is a nature photographer who specializes in pictures of animals in motion, and that is mostly what he presents in this portfolio of his work over a span of three decades. The pictures are spectacular, testifying to his skill and patience as a photographer. Dalton first gained his experience of animal motion by photographing bees in flight. Here he shows a great variety of animal movement—by insects, birds, bats, a Mediterranean chameleon and several other creatures. In the accompanying captions he describes the habits of each animal, and in a running text he writes of the photographic techniques he has developed for catching the often elusive creatures as they go about their business.

FROM *SECRET WORLDS*

ABSOLUTE ZERO AND THE CONQUEST OF COLD. Tom Shachtman. Houghton Mifflin Company, New York, 1999 ($24).

Shachtman, author of nonfiction books on a variety of subjects, holds the reader's attention with the skill of a novelist as he relates the 400-year effort to fill out what scientists have called "the map of Frigor," depicting the contours and characteristics of cold. In the early 17th century, when he begins his tale (with a demonstration by Cornelis Drebbel to King James I that a space in Westminster Abbey could be artificially cooled in the summer), no one "could conceive that there could ever be a connection between artificial cold and improving the effectiveness of medicine, transportation, or communications, or that the mastery of the cold might one day extend the range of humanity over the surface of the earth, the sky, and the sea and increase the comfort and efficiency of human lives." Shachtman describes the work of such luminaries of cold as Robert Boyle, Sadi Carnot, Carl Linde, James Dewar and Kamerlingh Onnes and ends with the achievement of a team at Harvard University that in February 1999, working with a Bose-Einstein condensate and laser-cooling techniques, produced "an environment only 50 billionths of a degree above absolute zero," wherein they slowed the speed of light to "a mere 38 miles per hour."

ORIGINS OF LIFE. Freeman Dyson. Cambridge University Press, 1999 ($12.95).

The plural of the title is purposeful: Dyson advances the hypothesis that life had a double origin. "Either life began only once, with the functions of replication and metabolism already present in rudimentary form and linked together from the beginning, or life began twice, with two separate kinds of creatures, one kind capable of metabolism without exact replication and the other kind capable of replication without metabolism." He sees reasons to favor the second possibility, with metabolizing creatures appearing first. Dyson is a renowned theoretical physicist (professor emeritus at the Institute for Advanced Study in Princeton, N.J.) who offers an "apology for a physicist venturing into biology" by citing physicist Erwin Schrödinger's maxim that "some of us should venture to embark on a synthesis of facts and theories, albeit with second-hand and incomplete knowledge of some of them, and at the risk of making fools of themselves." In this new edition of a book first published in 1985, Dyson builds his argument with characteristic skill and clarity. He views his hypothesis as "useful only insofar as it may suggest new experiments."

THE WIN-WIN SOLUTION. Steven J. Brams and Alan D. Taylor. W. W. Norton & Company, New York, 1999 ($24.95).

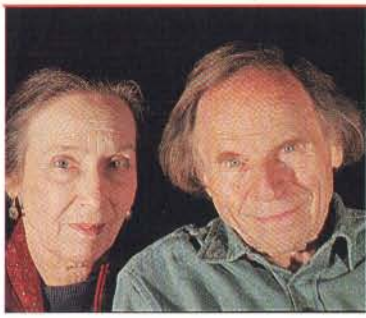
"Our concern in this book is with disputes—from divorce to business to international—in which *everybody* can win." Having thus precisely stated their objective, Brams (a professor of politics at New York University) and Taylor (a professor of mathematics at Union College) lay out a series of procedures whereby disputants can carve up the assets or issues and walk away convinced that the outcome is fair. Two of the procedures—strict alternation in choosing and divide-and-choose—have a long track record; Brams and Taylor offer them with some new modifications. The third procedure, adjusted winner, is their own.

"Under this procedure, the two parties begin by independently (that is, secretly) distributing a total of 100 points across all the items to be divided, depending on the relative value they attach to them." The one who put the highest value on a particular item gets it temporarily. Probably one party will win items adding up to more points than the items won by the other party. Then they start transferring items between themselves, in a certain order, until the point totals are equalized—that is the adjustment. The authors describe how their program would work for various kinds of disputes, ranging from the recent divorce of Gary and Lorna Wendt all the way back to King Solomon's division of a disputed baby. They think their procedures "can help parties reduce the frustration, anger, and occasional violence that often accompany escalating demands and endless haggling."

THE DECLINE OF MALES. Lionel Tiger. Golden Books, New York, 1999 ($23).

"The news overall is that women are taking firmer control of their destinies," Tiger declares. The result he sees is that men are losing their ancient position of dominance. How has this shift come about? Tiger, a professor of anthropology at Rutgers University, says the fundamental reason is that "through effective contraception—for the first time in history—one sex can control the reproductive process." And so "more women are having children without men, and therefore more men are without the love of families. Women as a group are working more and earning more. Men are working less and earning less." Moreover, women are now graduating from college at higher rates than men (a trend that will affect the future of employment) and have begun to vote in patterns distinctly different from the voting tendencies of men (a trend that will affect government and public dialogue). As for men, "what is under way is so imprecise but so general and atmospheric they do not realize what is happening to them." SA

FROM *THE DECLINE OF MALES*



WONDERS

by Philip and Phylis Morrison

Roll Back Malaria

DUSAN PETRICIC

A neat century back, in the first months of 1900, Italian epidemiologists carried out a rarely direct experiment. They engaged reliable families who lived in malarial regions and protected each home with tight screening, on condition that the family would remain indoors from sunset to sunrise. Malaria struck only 10 among 207 well-screened experimenters, whereas 44 of 51 unscreened next-door neighbors fell ill as usual. No doubt remained: it was the excludable mosquitoes that brought the ancient periodic fever, important then even in Rome.

This logic of exclusion is witty. The screens kept mosquitoes out—and malaria. We need to recall the originator of the logic, Francesco Redi, court physician of Florence. Long ago, in 1668, he exposed fresh meat out of doors behind a gauze screen. Flies came, and maggots thrived on unscreened meat nearby but not on the screened morsel. Spontaneous origins, dust and air could not cause maggots, for the mesh had not stopped them.

By 1900 we knew that malaria, too, was the work of microscopic parasites, and now we know their intricate double life. First, they multiply sexually within the infected mosquito. Once the female injects them into the human bloodstream, the organisms seek the cells of the liver, sooner or later to emerge and enter the red blood cells. There they divide again and again asexually by fission until they burst out, to begin an epidemic among red cells in many billions. The periodic fever and chills are signs of repeated significant loss of those cells, their essential red hemoglobin eaten away within, an acute partial anemia. The famous recurrences after some days of respite follow from timed emergence of the teeming parasites as they ripen in concert one evening to match the schedule of their nocturnal couriers. Back in a mosquito, the tiny forms mate and multiply, to crowd into the salivary glands of the blood thief, who may then inject them into another human during the blood meals that nourish the next egg-laying forays.

All this dovetailing is the elegant product of coevolution. Here is no recent affliction like the new human immunodeficiency virus (HIV). Many mammals, birds, even reptiles fall to a similar mosquito-borne disease, plausibly much older than our species, possibly a disease of our ancestral primates. Four distinct species of the human parasite are known; a few far-flung mosquito species within one large mosquito genus of anophelines ferry most of the organisms from person to person airborne.

In the mosquito-harboring world, some 100 bites per year is an average human burden.

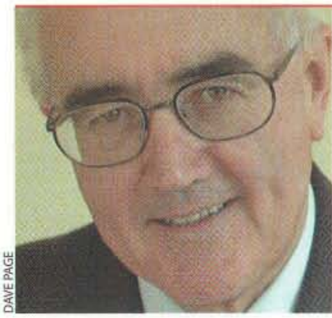
How engage this complex enemy? First of all, the human genome itself adapted to the selection pressure of the infection. Many people of West African origin bear a biochemical genetic trait not common elsewhere. Their hemoglobin is slightly modified: resistance to infestation appears, usually at minor cost in function. Experience everywhere had suggested the unhealthiness of wetland living; part of that concern was the mosquitoes it brings. Of course, no one enjoys mosquito bites. Screens exclude the fliers, and defense by bed netting close around sleepers is even less expensive. (Recent improvement has followed new netting impregnated with pesticides.) Drained wetlands, sewers and paved streets, animals kept at a distance, tight housing, less outdoor work, drugs and clinical help are now easily available. Together such changes have banished mosquitoes and malaria in well-off countries. Warm, wet climates are the major concern, yet not so long ago malaria was a summertime risk even in Denmark.

Finally, we combat the parasites themselves. The bitter Peruvian cinchona bark, a wide-spectrum natural plant defense against many enemies, was soon purified into quinine and much modified became chloroquine, the chief malarial preventative of the recent decades. (The Sunday-to-Sunday pill is still routine—one every seventh day and don't forget, we told ourselves in the late 1990s in both South Africa and India.) Effective new drugs, such as artemisinin, derived by Chinese pharmacologists from a traditional herbal remedy, are also at hand.

One graph in the World Health Report of 1999 (WHO) estimates losses to malaria since 1900; we use their figures. In 1930 the regional sub-Saharan risk of death by malaria was comparable to, if somewhat larger than, the risk in the rest of the world. By 1970, after an intensive worldwide campaign, the sub-Saharan risk had indeed fallen by more than half, although it lagged the much faster decline outside the region. By 1997 sub-Saharan malaria had counterattacked. While regional risk almost doubled, the world risk fell very steeply. Sub-Saharan personal risk of fatal malaria is now 160 times greater than it is outside. Nearly a million die every year in that region alone, six times the total of malarial deaths in the entire world.

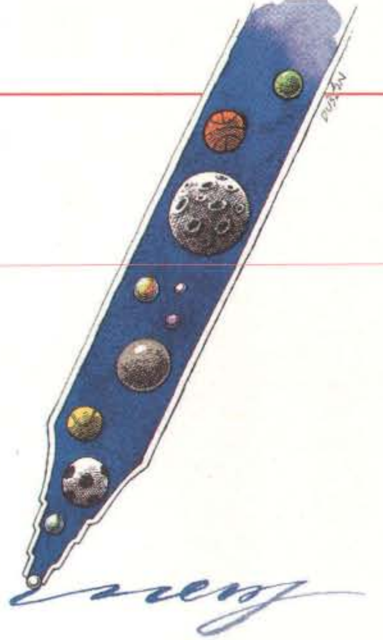
Why? In the mosquito-harboring world, some 100 bites per year is an average human burden. But an unprotected West African is likely to receive 1,000 bites a year. Sub-Saharan Africa is malaria's homeland; there ecology, cli-

Continued on page 87


DAVE PAGE

CONNECTIONS
by James Burke

On the Ball


DUSAN PETRICIC

Recently the guy next to me on the plane suddenly uttered an oath and stood up to reveal that his fountain pen had flooded. I felt smug, scribbling away with my little ballpoint pen, silently thanking the Hungarian who in the 1930s turned from hypnotism and editing a magazine to produce what we Brits still call, after him, the "biro." And because Lazlo Biro's amazing new pen didn't flood at altitude, World War II Allied Air Forces bought a zillion so their bombers wouldn't have to navigate to, and obliterate, a blot on the map.

Biro's war-winning gizmo used a tiny ball bearing to deliver ink to the page. King of ball bearings (as I bet you were desperate to know) was R. Stribeck, a German professor who a few decades earlier had submitted small metal spheres to every known indignity to find out how they would take the pressure of a ball bearing's working life. Discovered all kinds of groovy stuff like the importance of grooves for the ball to sit in. In the world of those who manufactured anything industrial that went round and round, Stribeck was a real mover.

So, too, was the man who told them how to lubricate those little balls. He being an absent-minded English prof name of Osborne Reynolds. Real kook. If something slipped, slid or flowed in the late 19th century, Reynolds did the numbers on it. He was the man who came up with the idea that depending on your design, there was a critical velocity at which the airflow over your wing would become so turbulent you would start to fly like a brick. Reynolds produced a formula that pulled together all the relevant factors involved in avoiding such an aerodynamic anathema when you were building your flying machine.

This *was* all theoretical, because nobody had actually flown at the time, but it became instantly practical at Kitty Hawk. Which was where the assiduous study of Reynolds numbers saved the Wrights from a nosedive into the sand. (Funnily enough, the Wrights were also into ball bearings; their day job involved running a bicycle shop.)

Mind you, I wouldn't even be mentioning the Wright brothers at all had life not dealt a lousy hand, two years earlier, to one of those individuals whose name might have become a household word but didn't: Wilhelm Kress. Alas for Wilhelm, you won't find him in the Aeronautics Hall of Fame. Kress was a piano maker turned engineer, and in October 1901 the 68-year-old wannabe from Austria (his emperor was offering a big prize for the first powered flight) opened the throttle on his three-winged floatplane and accelerated out across the surface of a reservoir near Tulln. In the event...well, there was no event. Kress never made it off the water (into the air and the history books) because by some oversight his engine was nearly twice as heavy as he had specified. Some oversight!

Jefferson's response to French remarks about wimpy American fauna was to send a stuffed moose.

Still, the apologetic Daimler company did better when they supplied their engines to yet another intrepid birdman. This one's efforts didn't bomb quite the way Kress had. No. Count Ferdinand von Zeppelin bombed in a rather different way. Thanks to the Mercedes engines powering the propellers on his World War I airships, the German air force was able to fly over and flatten bits of London with impunity (too high for defense fighters to reach them). And the 20-mile-per-hour gasbags did the good work in all weathers, because the airship balloon envelope was made of waterproof rubberized cloth, the first commercial example of which had, ironically, been invented in Britain. Two sheets of cotton with rubber sandwiched between them was the idea of Charles Macintosh, of whom I have spoken too much, so let me just say that his maternal uncle was John Moore. Moore was one of those guys you probably don't know but who knew all the people you *do* know (like Byron, Smollett, Frederick the Great, Bonnie Prince Charlie et al.).

Fortunately for this column, Moore also knew the great Scots poet and man for all seasons Robert Burns. I can't resist presenting for your delectation a couple of his lines: "O wad some power the giftie gie us/ To see oursels as others see us." I also can't resist mentioning that he and Beethoven shared the same London agent and that the agent's granddaughter married Charles Dickens (and, I have a feeling, will feature in some future column. Too good to ignore, that one).

On to Burns, however. In spite of the "genius plowman" myth, the poet was a well-educated polyglot and paid-up member of the Edinburgh chattering classes. One of whom was a pal of Burns, a slovenly dressed type who enjoyed the unfortunate name of William Smellie. Apparently undaunted, Smellie made a career out of philosophical musings, Scots antiquities and a printing business that put together the first, three-volume *Encyclopedia Britannica*. In 1765 Smellie's monograph on plant sex got him a

gold medal from somebody, and in 1781 he translated and edited a nine-volume version of a 36-volume French mind-bender entitled *Natural History,* by Georges-Louis Leclerc, Comte de Buffon (I wonder what he thought of being translated by a man named Smellie). Buffon huckstered the preevolutionary-theory notion of the Great Chain of Being, in which all forms of inorganic and organic life were linked in gradations all the way up from slime to angels. Truffles, for instance, were the intermediate stage between stones and mushrooms.

Buffon's adherents had a great row with Thomas Jefferson, who got all worked up by their remarks about America being full of syphilis and poisonous fogs and, above all, wimpy fauna. Jefferson's response to this last was to send them a stuffed moose. At the time, Jefferson was also busy reporting to President James Madison on the hot new phosphoretic matches. Which didn't make a really striking impact until the mid-19th century, when the Swedish Lundström brothers patented the now familiar safety version. By this time, however, phosphorus was being used for more down-to-earth purposes, after German agricultural chemist Justus von Liebig had found out farmers would get more bang for their buck if they put certain minerals in their soil, such as phosphates, and almost at one stroke solved the problem of how to feed the rocketing industrial population.

Liebig's was pretty much the first industrial chemistry lab, and he taught a generation of test-tube noodlers how to do research. Including August von Hofmann, who decamped with Liebig's teaching methods to England, where he stayed for 20 highly successful years, ran the new Royal College of Chemistry, and inspired a young man named William Perkin to dip into coal tar and discover the world's first artificial aniline dye.

Aniline dyes turned the world instantly Technicolor. Except for the world of books and newspapers, where cheaper, mass-produced aniline ink helped to keep many a printer's accounts (and his products) nice and black. Some decades later the new aniline inks revealed another attractive feature. When mixed with a solvent, they were quick-drying. Just what a certain Hungarian wanted for his new ballpoint pen.

Back to my scribbling. SA

Wonders, continued from page 85

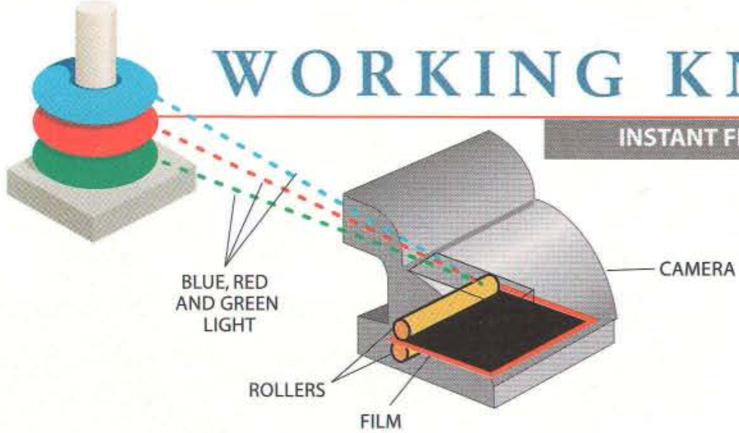
mate and land use all favor fast transmission of the disease, as does general disorder. The world antimalarial campaigns of mid-century rested on simple measures of control: both prophylactic drugs and the now suspect insecticide DDT, peculiarly effective against mosquitoes, were cheap. Success was sweet but uneven. The strategy eventually turned into a strong selection among mosquitoes favoring resistance to DDT and among parasite species for resistance to common drugs. The rarer malignant strain of malaria has in many places become abundant, probably a more recent adaptation to human infection than the common forms. Drug doses effective against it have been unaffordable to poor farmers; debilitated and fearful, they are unlikely to become better off. The decision that endemic African countries would not require a special campaign had led along a trail of linked feedbacks straight to regional disaster.

Molecular biology holds the wild card: immunization. But the enemy, the malarial parasite, is no virus, no bacterium, but a unicellular protozoan, its cells rather animallike, growing to some 10 microns. It is a eukaryote, like us, with a true cell nucleus and a chromosomal apparatus for maneuvers that make new combinations among 6,000 mapped genes. Armed as well with a battery of sensory organelles at its front end, it searches out and affixes to its prey, your red cells. Different progeny of a single infectious entry adhere differently. No one surface protein is vital to this hunt. The parasite can even change its protein spots. Unaided, the human immune system has never done much against malaria. We have little hope to win now by blocking one receptor with a single gene change; the experts work with dozens of new proteins to induce the complex mix of antibodies needed.

WHO has now targeted malaria again, right in its last stronghold, in Africa south of the Sahara. Operation Roll Back Malaria is under way. Health systems in place will be improved, multiple drugs will be made available and widely resupplied, and the world, with private and public sectors beginning to work together, can reasonably expect to halve the million annual deaths from African malaria at a bargain cost of about $1 billion a year, until some high-tech vaccine shall come to end the war. SA

WORKING KNOWLEDGE

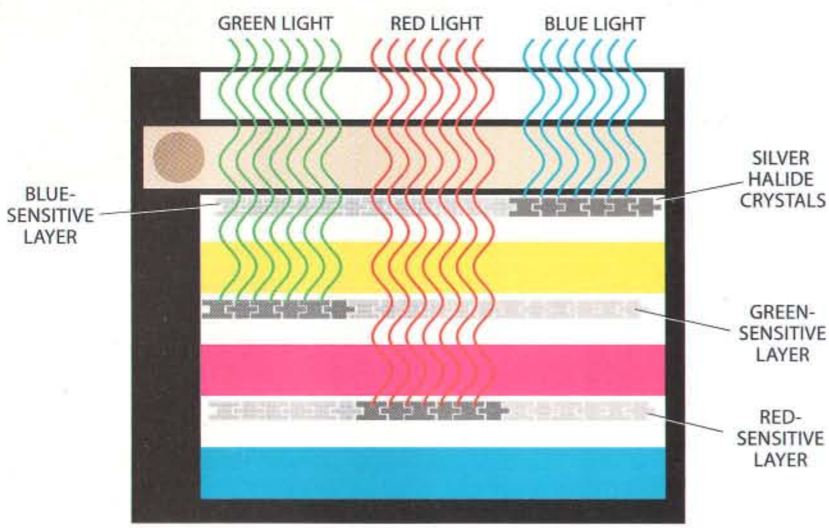
INSTANT FILM



by Stephen R. Herchen
Division Vice President, Research and Development at Polaroid Corporation

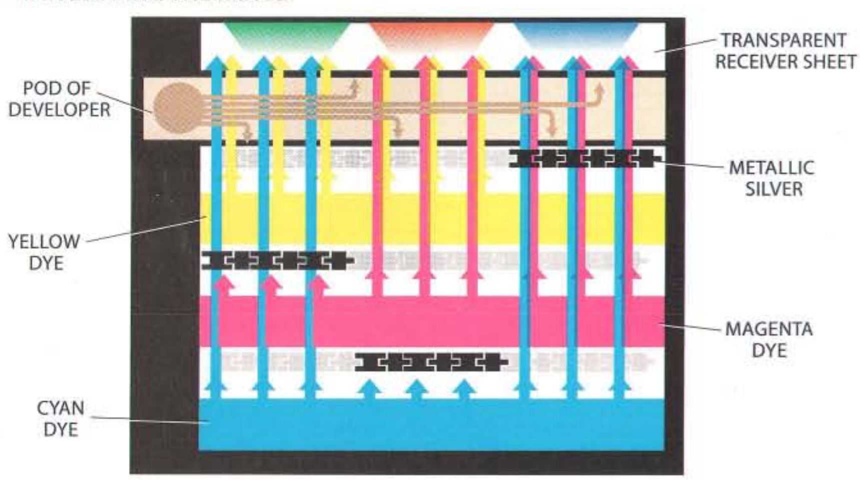
1 **INSTANT FILM** performs all the functions of a developing lab but in a fraction of the space and time. Each piece of film has three parts: a light-sensitive negative, a pod containing alkaline developing fluid and a transparent receiver sheet. Red, green and blue wavelengths of light from a scene penetrate the film until each hits a specific layer in the negative, causing minute changes to the chemical composition of silver halide crystals. The camera ejects the exposed film, passing it between rollers that break open the pod of developing fluid and spread the contents evenly across the frame. The fluid contains a white pigment on top of which the final color image will sit, as well as opacifying dyes that keep the negative in "darkroom conditions" outside the camera by absorbing ambient light.

EXPOSING THE NEGATIVE



2 **THE NEGATIVE**—typically made up of 16 chemical layers, each about one thousandth of a millimeter thick—absorbs the developer, which converts the exposed silver halide crystals into metallic silver. The developer also triggers the release of magenta, cyan and yellow dyes contained in other layers. (Almost all color photographs—instant, slide or regular print—use only three dyes.) The dyes travel toward the receiver sheet but are sometimes immobilized. Cyan dye passes through unexposed areas of the red-light sensitive layer, but chemical interactions with the silver prevent its passage where the red-sensitive layer has absorbed red light. The yellow and magenta dyes, however, are unaffected by the red-silver development, so they move freely, blending to create red when they reach the receiver. Similarly, magenta dye movement is thwarted in areas exposed to green light—but cyan and yellow dyes are not, and they blend to create green. Finally, yellow dye—although its chemistry is slightly different—is impeded by blue exposure, whereas cyan and magenta dyes reach the receiver and create blue.

DEVELOPING THE IMAGE



ILLUSTRATIONS BY BRYAN CHRISTIE

3 **AFTER A FEW MINUTES,** a layer at the bottom of the negative releases acid, deactivating the developer. The acid also renders the opacifying dyes in the receiver sheet transparent, allowing the image to be seen clearly. Shaking your print as it is "drying" does no good: it can only interfere with the even distribution of the developer and cause picture defects.